State of California
The Resources Agency
Department of Water Resources
Northern District

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FOREWORD

The Department of Water Resources strives to enhance recreation and fish and wildlife values at State Water Project facilities. Nowhere is recreation a higher project purpose, however, than at the Department's Upper Feather River Reservoirs in Plumas County. The Department continues to improve recreation and environmental resources at these reservoirs and in the Feather River watershed.

It is widely known that sport- and non-game fish can leave a reservoir via spillway releases. DWR personnel have repeatedly observed anglers taking advantage of this phenomenon, especially at Indian Creek below Antelope Reservoir, also observing that over a short period of time an exceptional stream fishery is greatly diminished. A better understanding of the causes and influences of such fish migration would give fishery and reservoir managers an additional tool with which to optimize benefits and minimize impacts of reservoir operations. Such knowledge may also be helpful in efforts to reduce impacts of some large stream diversions.

Northern District personnel studied Antelope Reservoir spillway fish emigration during March and April 1995, taking advantage of the design of the Antelope Reservoir spillway to implement a method of trapping and periodically counting all medium- and large-sized fish passing out of the reservoir. This report summarizes that investigation and presents the results in the context of other local fishery and recreation information the Department has collected in recent years. It also provides insight into the status of Antelope Reservoir and Indian Creek fisheries. The findings are especially timely given the State's desire to prevent northern pike from leaving Lake Davis.

This work was performed under the Department's Recreation Planning and Implementation Program (Upper Feather River Monitoring) and included services provided under a contract with the Department of Fish and Game's Bay-Delta and Special Water Projects Division. The results of this work will subsequently be made available to the fisheries science community through submission for publication to the North American Journal of Fisheries Management.

William J. Bennett

William J. Bennett, Chief
Northern District

TABLE OF CONTENTS

APPENDICES

TABLES

FIGURES

STATE OF CALIFORNIA
Pete Wilson, Governor

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Douglas P. Wheeler, Secretary for Resources

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David N. Kennedy, Director

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EXECUTIVE SUMMARY

In 1995, Department personnel counted and evaluated the emigration of fish from Antelope Reservoir through the spillway. Observers are aware that many fish left the reservoir in this manner in the past, but this phenomenon was never adequately qualitatively or quantitatively described. Furthermore, this phenomenon occasionally occurs at other reservoirs; anecdotal evidence and several years of creel census and fish population data indicate similar fish migrations have occurred at all three Upper Feather River State Water Project reservoirs (Antelope, Lake Davis, and Frenchman). Fisheries science literature in general does not adequately describe or explain the escape of fish over spillways.

This study was divided into three main phases: 1) collect, identify, mark, and release fish passing over the Antelope Reservoir spillway from the commencement of seasonal spill until the beginning of the downstream (Indian Creek) fishing season; 2) conduct a creel census along Indian Creek to evaluate the contribution of spilled fish to the downstream fishery; and 3) conduct fish population sampling along Indian Creek near the end of the fishing season to investigate the persistence of reservoir fish in the stream fishery.

Ten species of fish, predominantly a combination of cold- and warmwater sport fish, were collected during the seven week first phase of the study. In order of frequency of occurrence, largemouth bass (*Micropterus salmoides*), redear sunfish (*Lepomis microlophus*), black crappie (*Pomoxis nigromaculatus*), rainbow trout (*Oncorhynchus mykiss*), green sunfish (*L. cyanellus*), Eastern brook trout (*Salvelinus fontinalis*), bluegill (*L. macrochirus*), brown bullhead (*Ictalurus nebulosus*), hitch (*Lavinia exilicauda*), and part of one speckled dace (*Rhinichthys osculus*) were observed in the spillway. Record high spillway flows following the study (May 1995) apparently also passed channel catfish (*I. punctatus*) from Antelope Lake to Indian Creek. A very large, apparently lake-origin Sacramento sucker (*Catostomus occidentalis*) was observed in one reservoir tributary. At least three other species of fish (brown trout, *Salmo trutta*; smallmouth bass, *Micropterus dolomieui;* Lahontan redside, *Richardsonius egregus*) are also believed to occur in Antelope Reservoir but were not observed during the 1995 study. Almost two thousand fish were collected during emigration, identified, measured, marked (if still alive) and released into Indian Creek.

The study showed that the rate of sport fish emigration over the reservoir spillway was usually directly related to the stage of the spill and was predominantly a nocturnal event. Relatively few fish passed over the spillway when reservoir surface elevation was less than 0.8 feet above the spillway crest. Other measured and observed variables, such as air and water temperature, weather conditions, and lunar phase had no obvious correlation.

Only one marked fish was observed during the subsequent creel census. This low recovery was due collectively to record high streamflow at the beginning of fishing season, surprisingly low numbers of trout (the anglers' primary target species) emigrating from the reservoir, and unexpectedly high mortality induced by the collection technique. However, additional reservoir-origin trout were observed in the creel census, apparently having emigrated after the first phase of the study was completed. No marked fish were recovered during late-season fish population sampling, and very few fish collected during downstream sampling were otherwise determined to be of reservoir origin.

Fish which did emigrate from the reservoir to the downstream fishery generally only persisted in the fishery for a few weeks. Warmwater species (bass, crappie, sunfish) generally left the study reach or died. Very few large (reservoir origin) rainbow trout appeared in the creel census more than three weeks after spill dropped below 100 cfs (reservoir stage approximately 0.8 feet) and none were collected during late-season population sampling; most had likely been caught or had migrated downstream out of the study reach.

Fish passage was minimal at spill stages below 0.8 feet. Fishery and reservoir managers can use this finding to better coordinate reservoir operations and water supply objectives with fishery management objectives under certain circumstances. While such circumstances do not necessarily exist at Antelope Reservoir because of its relatively small capacity and large watershed, the two other Upper Feather River State Water Project reservoirs (and other large reservoirs) could be managed to encourage or discourage fish emigration to downstream areas. Such management could enhance one fishery over another or discourage the spread of nuisance or invasive fish species.

Designers can also use these findings to minimize the environmental impacts of water facilities. Although previous investigators have determined water velocity thresholds at which fish can avoid entrainment or impingement, or are encouraged to outmigrate, this study illustrates a "barrier" action produced by what is, in effect, a passive submerged structure.

This investigation also gives a useful insight into the current status of the Antelope Reservoir and Indian Creek fisheries. In general, reduced stocking rates and competition from recently-introduced warmwater fish species appear to have diminished the quality of the trout fishery over recent years. Several warmwater species are apparently thriving but are not significantly exploited by sport anglers.

INTRODUCTION

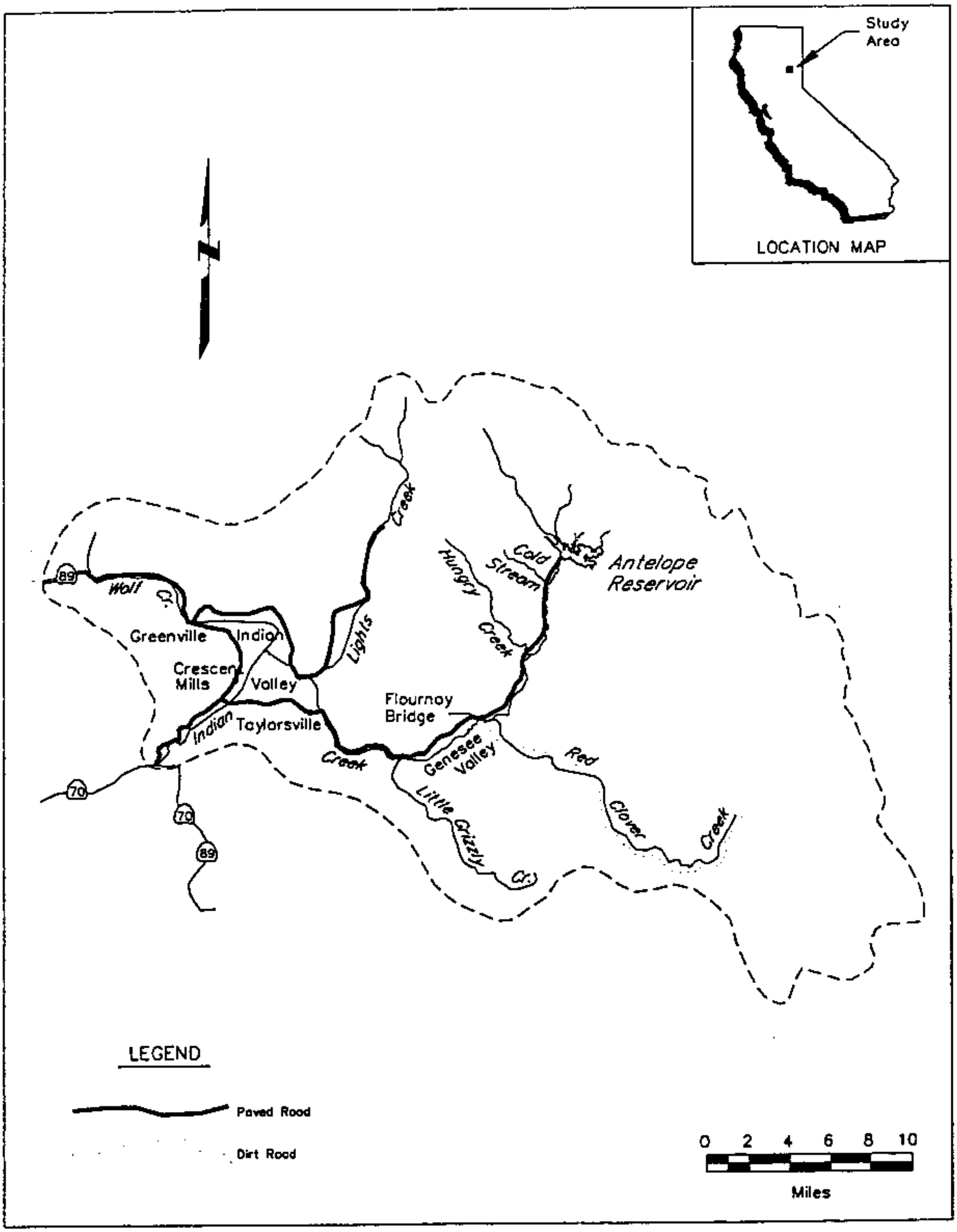
Fish have apparently passed over the Antelope Reservoir spillway into Indian Creek every year that the reservoir has had significant spill. Such fish are most apparent when caught by anglers early in the fishing season, which annually commences on the last Saturday in April. Numerous creel census and fish population surveys by the Department of Water Resources and the Department of Fish and Game have shown that this popular springtime fishery is predominantly composed of hundreds of mature/spawning rainbow trout which had overwintered in the reservoir after being planted during the previous year(s). These fish generally do not persist in the stream fishery very late into the season, most having been captured in the reach of Indian Creek immediately below Antelope Dam.

This investigation was designed to document the above phenomenon both qualitatively and quantitatively. Existing fisheries science literature sheds little light on what factors influence fish passage over spillways, and a greater understanding of such events will conceivably be useful to fishery and reservoir managers.

Location and General Features

Antelope Reservoir is about 24 miles east of Greenville in Plumas County (Figure 1). The reservoir is in the upper reaches of Indian Creek, a major tributary of the East Branch North Fork Feather River, and impounds a watershed area of 70.8 square miles. The Department of Water Resources completed Antelope Dam in 1964 to provide recreation and streamflow enhancement as part of the State Water Project. The earth embankment dam consists of two parts, both lined with large riprap on the reservoir side: a main dam embankment across Indian Creek which is 105 feet above streambed with a crest length of 740 feet, and an auxiliary dam (nearly adjacent) about 50 feet above ground level with a length of 580 feet. At spillway elevation (5,002.00 feet above mean sea level) the reservoir has a surface area of 930 acres, storage capacity of about 22,000 ac-ft, and a maximum depth of about 80 feet. Below Antelope Dam, Indian Creek flows

FIGURE 1. Antelope Reservoir: location and vicinity.



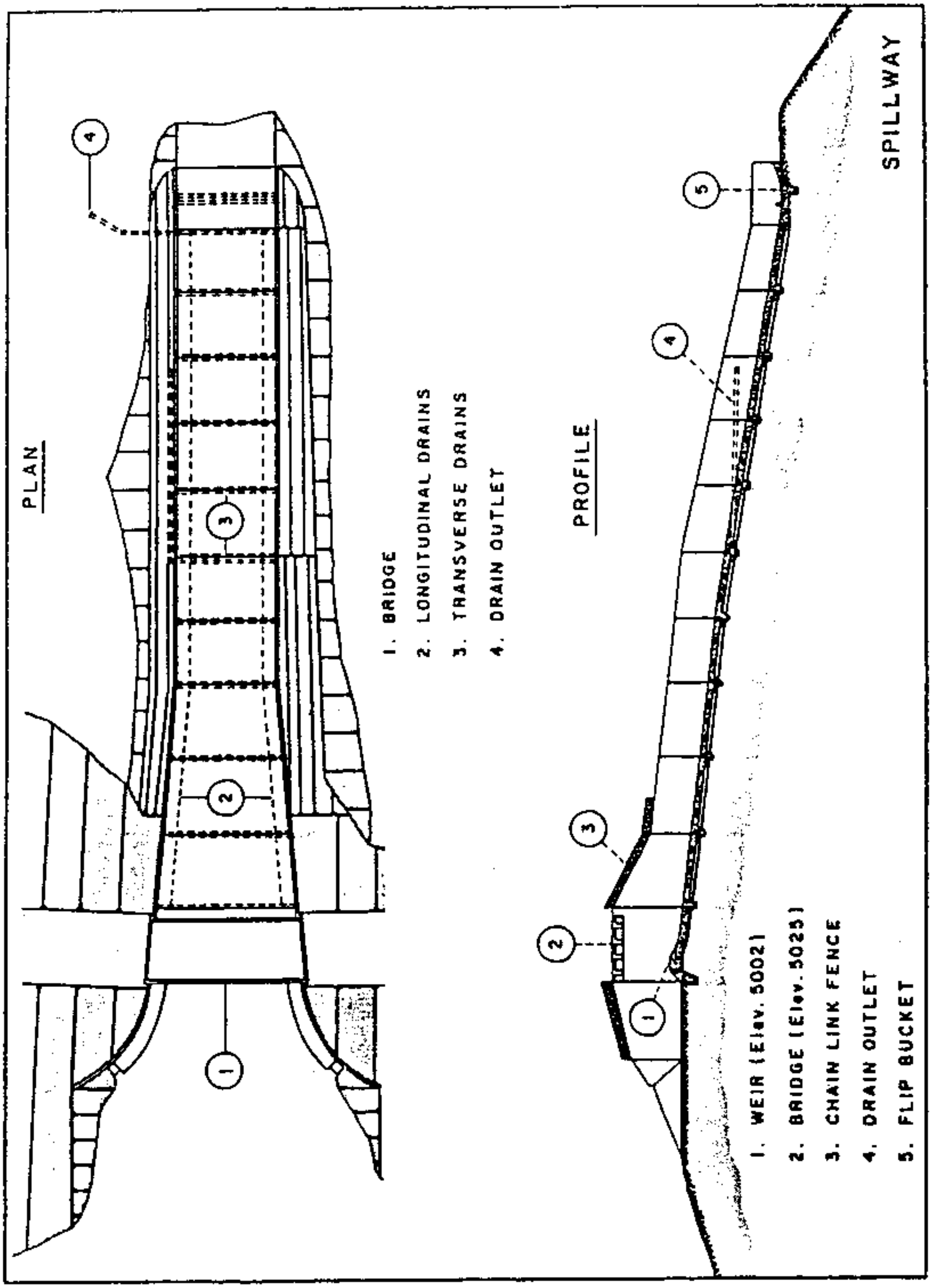
another 38 miles to its confluence with Spanish Creek near the junction of Highways 70 and 89, about 11 miles northwest of Quincy. The total watershed of Indian Creek below Antelope Dam is 687 square miles.

The Antelope Reservoir spillway (Figure 2) is located between the main dam embankment and the auxiliary dam embankment. It is reinforced concrete and consists of 1) a short unlined approach channel (proximal water depth 5 to 7 feet), 2) a convex 60-foot long ungated ogee crest structure, 3) a 110-foot long transition section of discharge chute that tapers from 60 to 40 feet wide, and 4) a 215-foot long discharge chute (slope 0.111 to 0.165) which terminates with a concave "flip bucket" 50 feet above the Indian Creek channel. The horizontal lip of the flip bucket, which is poised 40 inches higher than the lowest point of the spillway, creates a pool of water with a surface area of approximately 42 feet by 40 feet inside the spillway terminus. Water spilling over the terminal lip enters the Indian Creek channel below as a 50-foot cascading waterfall.

Because of the large watershed area relative to storage capacity, Antelope Reservoir fills and spills (uncontrolled release) in winter or spring in most years of at least 40 percent of mean annual precipitation/inflow. When Antelope Reservoir is not spilling, controlled releases are made to maintain Indian Creek. These releases are contingent on the June 1 water surface elevation. They are either 5, 10, or 20 cfs corresponding to water surface elevations below 4,998.00, between 4998.00 and 5002.00, or spilling, respectively. Under present operating conditions, summer releases for streamflow and environmental enhancement cause about 4 to 6 feet of annual change in the reservoir water surface elevation.

Downstream of the dam, the creek flows through a granitic canyon with stands of pine and fir and short reaches of meadow areas. It is closely followed by a paved road with wide pullouts for convenient stream access. A portion of the creek cuts through a deep and rugged canyon, accessible only by foot, before flowing into the upper part of Genesee Valley. The first 10 miles below the dam are within Plumas

FIGURE 2. Antelope Reservoir spillway: plan and profile views.



National Forest. The road within this area is not maintained for winter travel.

In Genesee and Indian Valleys most of Indian Creek flows through private ranch lands generally closed to public use. A few parcels of public land and points of public access are present. The creek is joined by several large tributaries and the gradient is very low in these reaches. Downstream from Indian Valley, the creek drops 500 feet in its last 7 miles, passing through a rugged canyon with some access to public lands along the highway.

The upper 11 miles of the stream remains cold in summer and is slightly turbid due to deep-water outflow from the dam. Brown trout and rainbow trout dominate the popular fishery, but many warm water sport- and non-game fish also occur, especially in the lowermost portion of this reach. In the 6-mile Genesee Valley reach, Indian Creek is characteristically clear and cool but can experience elevated temperatures on hot days. Typical summer minimum flows near the head of Genesee Valley are approximately 30 to 40 cfs.

Fish and wildlife resources at State Water Project facilities are managed by the California Department of Fish and Game. Antelope Reservoir is currently managed as a mixed trout-warmwater fishery, open all year around and popular in some years for ice fishing in winter with access by snowmobile. The fishing season in Indian Creek and other local streams and reservoir tributaries conforms with the general California Sierra District stream trout fishing season. It begins on the last Saturday in April and continues through November 15. Trout are normally the only species sought by anglers at Indian Creek.

Purpose and Scope

Although fishery resources at SWP facilities are managed by DFG, these resources are often affected by operating criteria of the respective dams and diversions. The Davis-Dolwig Act of 1961 (Water Code Sections 11900-11925) directed DWR to plan and provide for recreation and fish and wildlife enhancement at SWP facilities, and these efforts have taken many forms. At Antelope Reservoir, where the primary purpose of the facilities is recreation, DWR has attempted to optimize dam operation to maximize both reservoir and downstream recreation and environmental benefits because both are authorized project purposes.

This investigation was originally conceived to determine the magnitude and impact of the loss of trout from Antelope Reservoir over the spillway during the rainbow trout spawning season. Little information is otherwise available to describe either the spillway emigration phenomenon or the status of the fishery at Antelope Lake. It was not known if the number of fish "lost" over the spillway represented a significant percentage of the reservoir population. This investigation sought to provide information on these subjects which would be useful to State and other fishery and reservoir managers.

Rainbow trout, the most widely planted fish species in California, is arguably the most popular target of anglers. Like most salmonids, rainbow trout that survive to reproductive maturity require moving water and proper substrate (gravel) to spawn successfully. Rainbow trout are often relatively more successful at natural reproduction, since species which spawn in the fall (e.g. brown trout) typically have to contend with less streamflow (less habitat and greater barriers to migration) and winter freshets (which scour gravels). In lentic environments, trout normally migrate and seek tributary streams during the spring period of relatively higher streamflow and lower water temperature. In natural lakes, spawning habitat can also often exist at a lake's outlet. An outlet zone of proper water velocity and acceptable substrate can create a spawning and rearing area, and if the gradient is not too great, transmigration between the stream and lake can occur.

In reservoir impoundments, spill and the associated migration of trout over spillways often occur during spring and coincide with rainbow trout spawning season. Moving water is probably one important factor which attracts lake fish to potential spawning habitat, and instinctual spawning behavior in trout normally includes upstream and not downstream migration. Influenced by a dam and spillway, such behavior often results in crowding of spawning fish below the dam. A reservoir's spillway outlet area, however, does not usually contain useable habitat. For example, stream habitat below reservoirs has often been scoured of gravel substrate. Since the dam impedes recruitment of new gravel from the watershed, substrate for some distance below the dam is often not suitable for use by spawning salmonids. Alternatively, areas of spawning habitat appear to be present in several Antelope Reservoir tributaries.

When mature fish are attracted to a spillway area and swept downstream, the lake has lost fish that are of the highest biological and recreational value to the lake fishery. While both a reservoir and its outlet stream may provide popular sport fisheries, past studies at Indian Creek have indicated that rainbow trout reproduction below Antelope Dam is minimal, and large rainbow trout do not persist in this stream fishery very long into the year.

Intense fishing pressure at Indian Creek, beginning the last weekend in April, is believed to be in part responsible for reducing persistence and may affect reproduction. Unsuitability of substrate is probably also a significant factor limiting reproduction, especially since rainbow trout instinctively tend to swim upstream to spawn and thus are not normally observed dispersed more than half a mile downstream from Antelope Dam. Such concentrations of large fish can result in their rapid removal from the fishery by anglers, diminishing the quality of the recreational fishery during the remainder of the season.

By observing when fish pass over the spillway and measuring the physical parameters present during the period of emigration, this study seeks to identify conditions which trigger (and conversely, might prevent) such passage. The techniques of this investigation also allowed enumeration of all fish (greater than a minimum size) passing over the spillway. Another goal was to mark all captured fish, release them into the downstream fishery, and monitor their persistence in the fishery through a creel census and other sampling.

Previous Work and Overview of Management History

The DFG Region II office in Rancho Cordova maintains files of previous survey work and related resource issues dating back to at least 1951. Much of the information in this section was obtained from those files. DWR has also periodically produced reports describing various angler, creel, recreation, flow, habitat, fishery, and other surveys conducted at Indian Creek and Antelope Lake since 1979. Few papers have been published on the subject of emigration of fish over spillways.

Antelope Reservoir. Resources managers have responded to several diverse resource management problems in the Antelope Reservoir watershed during the last three decades. These included establishment of undesirable fish species in the reservoir which have degraded the recreational fishery; proliferation of aquatic plants overgrowing nearshore areas, which reduce aesthetics and recreation/boating quality; and episodes of acute and chronic erosion, with consequential sedimentation of the reservoir. Each of these resource problems have been studied by the respective resource agencies to some degree.

The fishery of Antelope Reservoir has changed dramatically over the years. Originally managed by DFG as a rainbow trout fishery capable of producing up to 120 pounds per surface acre annually, annual plants of fingerling trout could not capitalize on the reservoir's productivity because of predation and competition from other introduced species (golden shiner and brown bullhead). The reservoir was treated twice (1971 and 1976) with rotenone in unsuccessful attempts to restore the trout fishery, and since 1982 has been managed as a mixed trout-warmwater fishery on a "trial basis". Recommendations and proposals to use rotenone for a third time during the 1980s were indefinitely abandoned after intense public opposition.

Several areas upstream from Antelope Reservoir have been significantly impacted by past timber harvest and cattle use. DWR determined that watershed sediment contribution to the reservoir averages roughly 40,000 tons per year, most of it from Lone Rock and Indian Creeks in the northern arm of the lake. Sedimentation has reduced the reservoir's storage capacity by about 2 percent since construction

(DWR 1990). The U.S. Forest Service (Plumas National Forest) has implemented numerous programs and remediation efforts to reduce erosion in this and other Forest watersheds.

An area of acute sedimentation in Antelope Reservoir is adjacent to several PNF campgrounds and recreation facilities. The shallow area created by the nutrient-rich sediment provided an ideal site for proliferation of aquatic plants, which also spread around other shoreline areas, interfering with boating and area aesthetics. In 1976, as a strategy to freeze the aquatic plants and minimize the next year's regrowth, PNF recommended reservoir drawdown in conjunction with the second rotenone treatment. This management strategy was initially successful but the 1976-77 drought did not allow the reservoir to refill for two seasons. Consequently, regular drawdown was not pursued as a weed management technique.

Despite high yield of fine sediment from the watershed, tributaries to Antelope Reservoir appear to contain sufficient spawning habitat for lakerun trout. Local anglers, USFS staff, and DWR staff have observed large trout in Indian Creek upstream from the lake during spring spawning periods. Local anglers also report fry and fingerling trout trapped in intermittent, isolated pools of the tributaries during the summer of low-runoff years (L. Kingdon, personal communication). However, the total contribution of naturally-spawned trout to the lake fishery is unknown but probably minor.

Indian Creek. The current operating criteria for Antelope Dam are based on recommendations made following a 1976 instream flow study (Haines 1981a). After several years of initial operation, resource managers recognized that releases from Antelope Dam could be increased during summer months to benefit recreation and fishery values downstream without significant adverse effects on reservoir recreation values. Following implementation of proposed revised operating criteria in 1978, DWR implemented a three-year program to measure recreation and fishery use downstream to evaluate the benefits provided by augmented flow conditions (Cartier 1979a,b; Haines 1980, 1981b). These recreation and creel surveys covered Indian Creek from Antelope Dam to its mouth at the confluence with Spanish Creek and provided evidence that, under the revised flow schedule, Indian Creek trout populations had increased and more anglers were attracted to the area (Hinton and Haines 1981). Large benefits and negligible impacts of the revised operating schedule prompted DWR to adopt these criteria permanently.

Additional recreation surveys and creel censuses have periodically been conducted by DWR on the first 11 or 17 miles of Indian Creek below Antelope Dam (Hinton 1982, 1983; Tittel 1987; Brown 1990; Scott 1994; Rischbieter and Scott 1996). The nine years of recreation surveys, a period that included a wide range of streamflow conditions, have defined Indian Creek recreation and fishing quite well and also provided some interesting anecdotal information. Use is normally heaviest in the spring months; about 60 to 75 percent of the fishing, and 50 percent of the annual recreation (including camping and other leisure activities), occur by the end of June. The best fishing normally occurs before July. Most of the exceptionally large fish observed in the creel census are caught on the opening weekend or early in the season. The opening weekend always has the highest angling use of the year (typically 12 - 20 percent of the annual use) but often not the highest fishing success.

Creel censuses have also revealed that angling success is often higher and more anglers are attracted to Indian Creek in years when Antelope Reservoir spills and summer flows are maintained at 20 cfs than in years with low flows. Anglers expect rainbow trout to leave the reservoir when it spills and that fishing will be good downstream. Authors of Indian Creek creel census reports (Cartier 1979a; Hinton 1982, 1983; Tittel 1987; Brown 1990; Scott 1994; Rischbieter and Scott 1996) have thought that the catch per hour and total catch of rainbow trout roughly reflect the number of trout entering the stream at the time of spill. Fishing success for brown trout normally remains about the same irrespective of angling pressure. After spill ends, the higher maintained flows make the stream appear better for fishing and increased angler use continues.

In conjunction with the recreation monitoring, DFG personnel under contract with DWR sampled fish populations at various points along

Indian Creek and in the watershed with most study directed at the first 11 miles below the dam. Four to seven stations in this reach have been repeatedly sampled by electrofishing in 13 different years since 1977. Data demonstrate correlations between streamflow and standing crop and catch; age and growth relationships have also been described. Reports summarizing these studies (Brown 1993, 1994) also indicate that extremely high flows (spill), while often detrimental to Indian Creek resident trout populations, introduce fish from Antelope Lake into the stream fishery.

Escape of Fish over Spillways. An inquiry into the escape of fish over spillways was apparently first published by Clark (1942). Louder (1958), Elser (1960), and Lewis et al. (1968) each subsequently conducted similar studies targeting a small number of very small- to medium-sized Eastern and Midwestern ponds or reservoirs with warmwater fisheries. The duration of each study varied from a few months to several years, but most sampling only measured migration through a fraction of the outlet area.

Results of earlier studies give no clear indication of generalities applicable to escape of fish over spillways. The relative effects on various warmwater species varied, in some cases mirroring the relative abundance of species in the lake (Clark 1942; to a lesser extent Louder 1958) and in other cases an important lake species was greatly underrepresented. There is some consensus that volume of flow and depth of spill are of little or no influence and that seasonal/reproductive influences are of primary importance. However, sampling techniques varied and catch at similar reservoirs varied from hundreds to thousands to tens of thousands (estimated) of individual fish. Elser (1960) suggests that design of the spillway (including construction material) is the most important factor influencing emigration at one reservoir versus another; he postulated that turbulence at the lip of the spillway inhibits fish loss. Each investigator noted that their findings, though limited, may be very useful to reservoir and fishery managers. They all iterated that additional study would be desirable.

Current interest and thorough documentation of migration of fish through reservoirs, and passage over dams and through penstocks/turbines, has almost exclusively been related to passage of anadromous salmonids. Schoeneman et al. (1961), Leman and Paulik (1966), Sims et al. (1978), and many others have described these problems and possible solutions, primarily from the standpoint of salmon and steelhead fisheries of the Columbia and other Northwest rivers.

The lack of further published study on the general topic is surprising given that each early study raised more questions than were answered. Further documentation of the spillway emigration phenomenon apparently has not been conducted to describe physical influences directly at the point of emigration. Several papers, however, note such fish movement occurring within the scope of a broader or unrelated investigation. Huston and Vaughan (1968) recognized that management of rainbow trout populations in large multipurpose reservoirs is greatly complicated by attrition of the population downstream through spillways and turbines. Hansen (1971) trapped hundreds of planted cutthroat trout leaving a natural lake via its outlet between April and July. Stober et al. (1983) sought to reduce the entrainment of kokanee from a large reservoir where an irrigation canal intake previously entrained many tens of thousands of fish annually. These three studies collectively utilized a downstream creel census and/or placed a net, screen, or trap across all or part of the outlet stream/canal. Jahn et al. (1987) collected (using rotenone and electrofishing) many thousand gizzard shad and a few hybrid striped bass below a spillway over four years of a lake stocking study. A screen on the spillway in Jahn's study impinged gizzard shad; impingement decreased as spill decreased.

Several of the above-referenced investigators noted some public concern about fish being "lost" from lake fisheries but generally noted that such migration could be beneficial to downstream fisheries. Pfitzer (1967) describes tailwater areas below dams as often supporting fisheries with high recreational value.

METHODOLOGY

Fish Emigration Counts

The configuration of the Antelope Dam spillway prevents fish from returning to the reservoir once they have passed over the crest of the weir. Typical water velocity in the inclined chute rapidly delivers these fish to the shallow pool in the flip bucket, where they can spend varying amounts of time before swimming or being swept over the lip into Indian Creek. Under low and moderate spill conditions, stream anglers have been observed catching rainbow trout in this artificial pool.

This investigation sought to trap all fish leaving Antelope Reservoir via the spillway in the flip bucket, periodically collect them by various means including seining, dip-netting, or electrofishing, and mark them prior to releasing them into Indian Creek below the dam. To prevent fish from exiting the flip bucket pool, 2" x 6" wooden flashing was attached using 3/8" expansion bolts to the terminal outside edges of the spillway walls and lip. This wood surface then allowed temporary placement of a 40' x 6' net flush across the terminal end of the spillway, anchoring it between a second layer of 2" x 6" boards nailed firmly onto the bolted ones. The 1.5"-mesh barrier net was constructed of #84 heavy-duty knotted nylon, reinforced with nylon rope borders, and treated with a plastic coating to enhance durability. The net was installed two hours prior to the 1995 spill which commenced on March 9. Ropes were also attached to points along the top of the net and secured and tightened to reduce the amount of sag in the net's span.

Under most flow conditions, fish were not able to hold in the flip bucket pool. This was especially true of warmwater species, which almost invariably were swept into the barrier net and pinned there until collected by hand. Because of these circumstances, almost all removal of fish was done by hand usually twice daily, typically near dawn and dusk. On three occasions the net was emptied an additional time during hours of darkness. Extreme weather conditions occasionally prevented access to the site and some collections were delayed or postponed. For five of the first six days of the study it was not possible to safely access all 40' of the net because of flood flows, so only a portion of the net was emptied. The net was also cleaned of debris during each inspection.

Each check of the net took between a few minutes to more than an hour, depending on flow and debris conditions and number of fish present. After the net had been inspected and all pinned fish and debris removed, it was immediately double-checked to ensure that no fish had been missed. The approximate times of all such fish removal are summarized in Appendix A.

In a few instances and for varying reasons, removal of some or all fish was delayed for one or more days. In such instances, when dead fish were finally recovered from the net, it was generally possible to determine how many days (1, 2, 3, or 4) an individual had been trapped in the net by comparing relative degrees of early decomposition. Fish determined to have been dead for two days, for example, were counted among fish observed two days prior to recovery.

Under low spill conditions, it was possible to effectively electrofish the energy dissipation pool. After removing pinned fish from the net as described above, investigators electrofished (Smith-Root Type 12, 60 Hz, 400 or 500 VDC) for a long enough duration to methodically cover the entire volume of the pool, herding any fish into the net. This was done during 14 of the 89 collection occasions. After each electrofishing effort, the net was again checked for any fish that had drifted down. Fish collected during or immediately after electrofishing were included with counts of fish removed from the net immediately before electrofishing. Investigators also attempted to dipnet and seine in the energy dissipation pool under various flow conditions.

All fish collected were stored for the duration of the net check in a pail or garbage can with spillway water. Non-fish animals trapped by the net were also removed, identified, and counted. Immediately after the net was cleared, each fish was identified, measured (fork length to nearest 0.5 centimeter [cm])[1], marked if still alive with a single-hole paper-punch hole in the dorsal fin, and released into Indian Creek below the spillway. Any fish captured by electrofishing in the spillway was also marked with a punched hole in the caudal fin. Some fish which appeared to be either representative or unusually large were weighed, either individually or collectively, using a variety of spring scales and tared containers.

General weather and sky and water conditions, and flow/spill level, were recorded during each sampling episode. Reservoir water level, to the nearest 0.01 foot, was available as a digital readout at the dam and was corroborated by a staff gage near the spillway intake. Reservoir surface water temperature was measured (nearest 1°F) in the spillway; reservoir bottom temperature was measured at the outlet valve discharge. Air temperature was measured in the shade.

At several spill stages, investigators measured water velocity at depths of 1 and 4 feet in the unlined spillway approach channel (proximal water depth 5 to 7 feet) approximately 20 feet "upstream" of the weir. Measurements were taken at 9-foot intervals, beginning 2 feet from the wall on one side of the spillway, across the upstream side of the spillway using a Price current meter hung with a weight from a cable. The velocity of this water, in the vicinity of the spillway, was plotted against various spill stages to establish a relationship between spill stage and current velocity in the proximal lentic environment.

Sampling was conducted under a variety of flow/spill conditions as created by natural runoff. On several occasions, releases from the reservoir's two outlet valves (10" and 24") were adjusted (to either 20, 23, 131, or 154 cfs) to modify the reservoir surface elevation and either lower or heighten the spill stage. This manipulation allowed observation of a greater variety of flow conditions and also took undesirably high pressure off the net during some high flow periods.

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[1] To convey proper accuracy and precision, results of fish measurements are reported in metric units throughout this report. Measurements of structural features and environmental parameters will continue to be reported in units of English measure.

Angler Creel Census

A creel census was conducted in conjunction with recreation use counts on randomly selected dates within ten survey strata using the optimum allocation method described by Abramson and Tolladay (1959). Thirty days of the 201-day period from April 29 through November 15, 1995, were surveyed: both days of the opening weekend of trout season, 5 of 10 holiday weekend days, 11 of 139 weekdays, 10 of 48 general weekend days, and both days of the opening weekend of the general deer season (Appendix B).

Investigators interviewed anglers along 17 miles of Indian Creek (Antelope Dam to Shim Flat) to determine fishing success. The public road along the creek was driven at least five times each day between sunrise and sunset in search of stream anglers. As time permitted (most stream census dates, plus additional dates prior to the commencement of the stream fishing season), anglers encountered at Antelope Reservoir were also interviewed. The terminal gear, length of time spent fishing so far that day, and county of residence was recorded for each angler contacted. Fish censused were counted, measured (fork length to nearest 0.5 cm), and identified to species.

To determine total catch from Indian Creek, the catch per hour was multiplied by estimated hours of fishing for each stratum (Rischbieter and Scott 1996).

Fish Population Sampling

Several episodes of fish population sampling were conducted to gather anecdotal information about fish distribution near the controlled outlet of the reservoir, fish use of Antelope Lake tributaries during the spring, persistence of lake-origin fish in Indian Creek below the dam, and general Indian Creek trout population data. All such sampling was done with a backpack electroshocker.

A branch of the Indian Creek channel flows for about 275 feet from the outlet valve works to where it is joined by flow from the spillway. On April 4, 1995, in conjunction with a change in valve release, the upper 265 feet of this section was block-netted as valve flow was temporarily suspended. Two electrofishing passes were made under static water conditions to determine if previously marked fish were holding in this area and if any reservoir fish had been passed through the valves. Fish collected were temporarily stored in a pail, measured, marked (caudal mark only) and released.

Spot-sampling of likely fish habitat was conducted on April 19, 1995 in three Antelope Reservoir tributaries (Lone Rock Creek, Indian Creek, and Boulder Creek). Several hundred yards of each stream, beginning near their respective crossings of the main Antelope Reservoir road, were electroshocked at 400 VDC. Fish collected were temporarily stored in a pail, measured, and returned to the creek shortly thereafter.

Sampling of fish in Indian Creek below the dam was also conducted during September 1995. Spot sampling was conducted at various points about 0.3 miles from the dam. Also, standing stocks of fishes were estimated at six representative stations in Indian Creek ranging from 0.8 to 13.1 miles from the dam. Stations were selected to be near stations sampled in previous DFG studies (Gerstung 1973; Brown 1993). Stations varied in length from 123 to 220 feet.

For all standing stock estimates, fish were captured with a battery-powered backpack electroshocker in stream sections blocked by seines as described by Platts et al. (1983). Captured fish were removed from the net-enclosed section on each pass. Standing stock estimates were developed using the two-count method of Seber and LeCren (1967) or the multiple-pass method of Leslie and Davis (1939) with limits of confidence computed using a formula proposed by DeLury (1951), as employed by Brown (1994).

The weights of trout and some nongame fishes were measured by displacement. Fork length of each fish caught was measured to the nearest millimeter (mm).

RESULTS

Thirteen species of fish were observed during the course of the investigation. Ten species of fish, totalling 1,940 individuals, were collected from the pool and net in the Antelope Reservoir spillway. Table 1 summarizes species and total numbers of fish observed in the spillway net. Table 1 also shows the number of each species that were marked and released alive (537 total). Additionally, one very large (47 cm fork length, apparently lakerun) Sacramento sucker (*Catostomus occidentalis*) was collected in one reservoir tributary (Indian Creek). Record high spillway flows following the study (May 1995) apparently also passed channel catfish (*Ictalurus punctatus*) from Antelope Lake to Indian Creek; one extremely large (87 cm total length, approximately 11 - 14 kilograms [kg]) individual was observed during fish population sampling 4.2 miles downstream from the dam. Brown trout (*Salmo trutta*) were common in Indian Creek, but only one angler reported catching one in the reservoir. At least two other species of fish (smallmouth bass, *Micropterus dolomieui*; Lahontan redside, *Richardsonius egregus*) are also believed to occur in Antelope Reservoir but were not observed during the 1995 study. File references to pumpkinseed (*Lepomis gibbosus*) in Antelope Reservoir appear to be incorrect identifications of redear sunfish (*L. microlophus*).

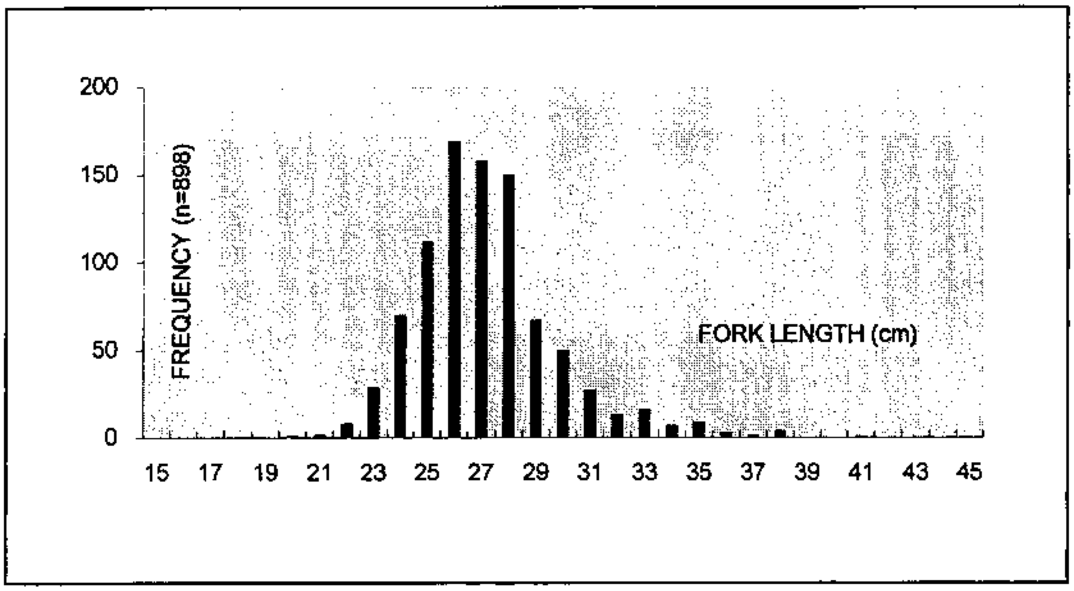
Typical recorded lengths of the six most abundant species are displayed in Figures 3A through 3F. The average largemouth bass collected weighed about 0.33 kg. The largest was 40.5 cm fork length and weighed about 1.4 kg. The bass appeared in good condition, but apparently invariably were infested with numerous parasitic nematodes in their mesenteries. The largest black crappie collected was 26 cm fork length and weighed about 335 gm, but most observed were not nearly this size. Average weights of other species were not calculated.

Several other species of animals were also recovered from the spillway net, most having apparently passed over the spillway. In order of

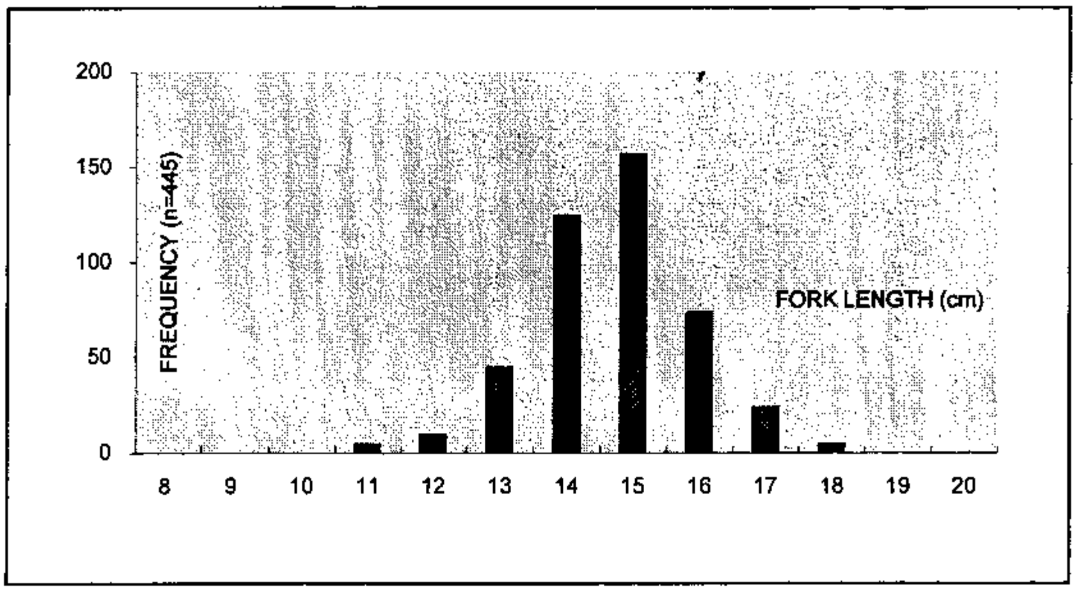
TABLE 1. **Species and numbers of fish captured in the Antelope Reservoir spillway and marked.**

SPECIES	NUMBER COLLECTED	RELEASED ALIVE (MARKED)
SALMONIDAE		
Rainbow Trout *Oncorhynchus mykiss*	115	38
Eastern Brook Trout *Salvelinus fontinalis*	13	1
CYPRINIDAE		
Hitch *Lavinia exilicauda*	2	0
Speckled Dace *Rhinichthys osculus*	1	0
ICTALURIDAE		
Brown Bullhead *Ictalurus nebulosus*	6	6
CENTRARCHIDAE		
Bluegill *Lepomis macrochirus*	7	3
Redear Sunfish *Lepomis microlophus*	634	136
Green Sunfish *Lepomis cyanellus*	35	4
Black Crappie *Pomoxis nigromaculatus*	199	21
Largemouth Bass *Micropterus salmoides*	928	328
TOTAL FISH COLLECTED	1,940	537

FIGURE 3. Length-frequency distributions of six species collected from the Antelope Reservoir spillway.

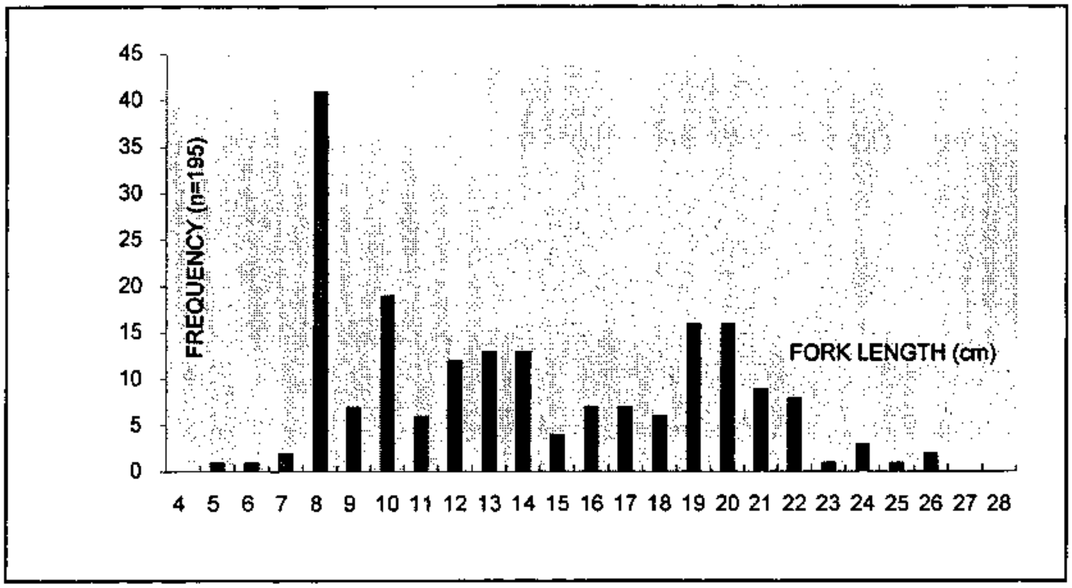


3A. Largemouth Bass

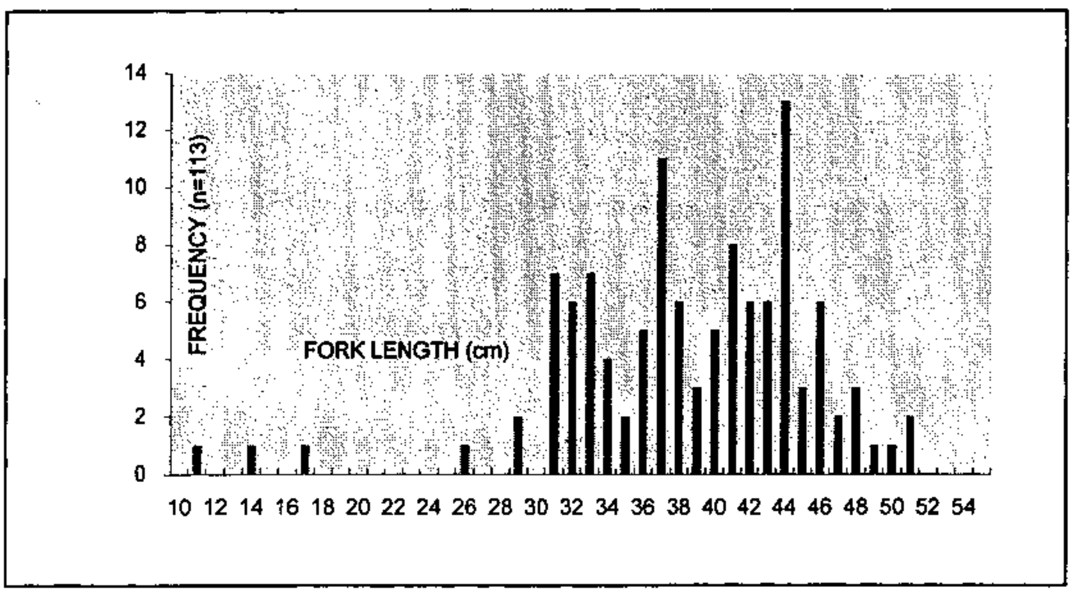


3B. Redear Sunfish

FIGURE 3 (cont).

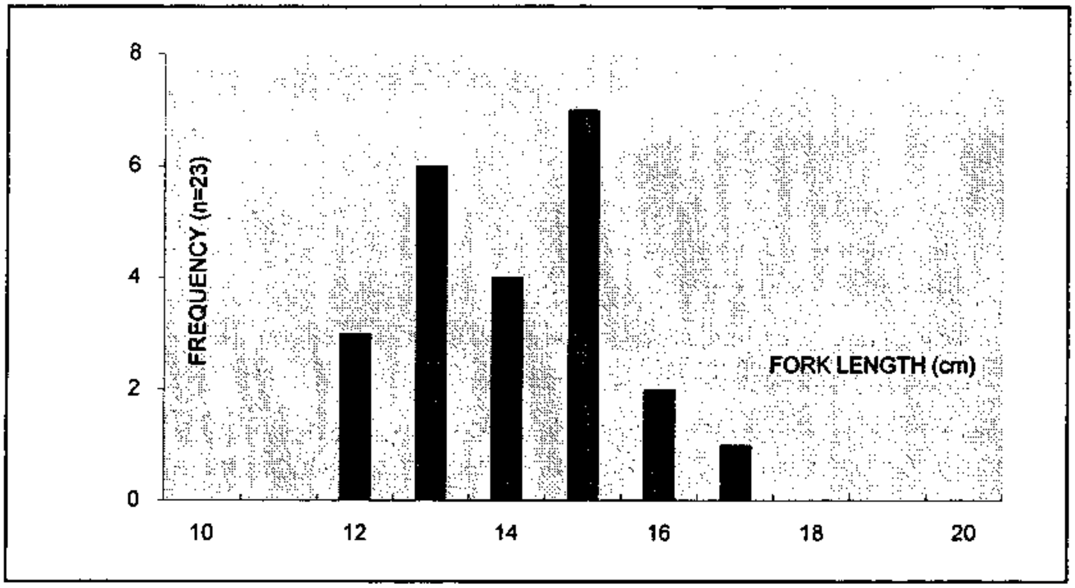


3C. Black Crappie

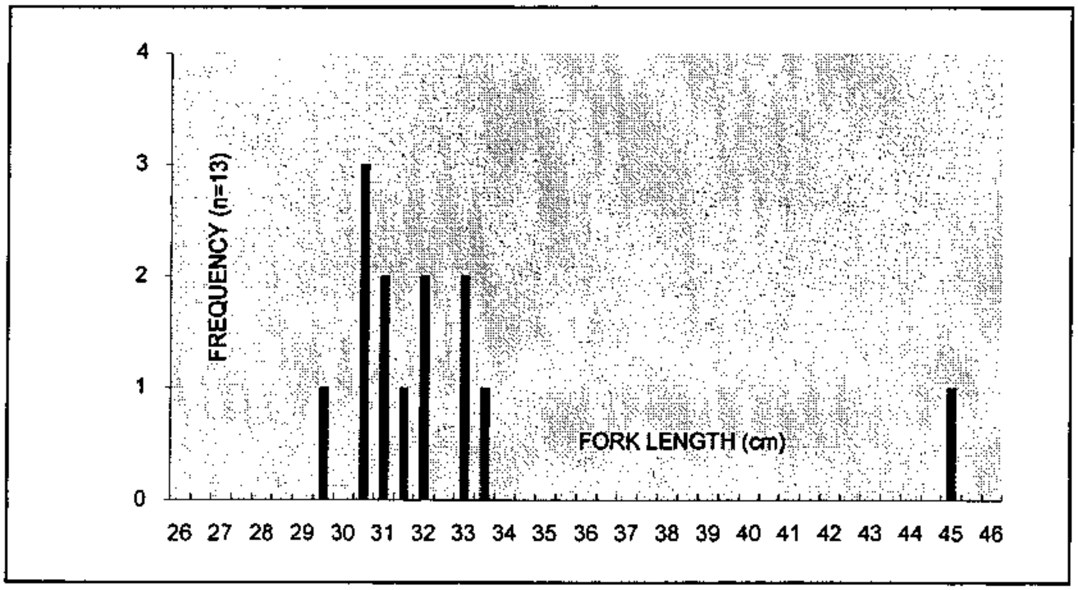


3D. Rainbow Trout

FIGURE 3 (cont).



3E. Green Sunfish



3F. Eastern Brook Trout

frequency while the net was in place, crayfish (44), meadow voles (7), muskrats (3), and one each unidentified brush mouse, grebe, cormorant, and swallow were observed. Most crayfish were released alive, but all mammals and birds were found dead in the net.

Rates of Spillway Emigration

The number of fish collected from the net and spillway pool during each of the 89 times the net was checked, and physical conditions recorded at the time, are summarized in Appendix A. Reported collections during March 11 through 15 are adjusted for fish which appeared to have emigrated more than one day prior to actual retrieval. During these initial days of the study, flood flows overtopped a portion of the center of the net by up to 6 inches. Until investigators raised the net to stop this problem, it was not possible to safely remove all fish from the middle one-fifth or more of the net on these five days. However, the flow pattern in the spillway under the overflow condition, and the configuration of the net bulging under such flows, probably did not allow fish to bypass the net. Thus, the net collected all fish which did not pass through the 1.5-inch mesh. By March 16 all such fish which had passed into the spillway since the net was last completely emptied (March 10) were accounted for.

Of the 1,940 fish collected from the spillway, only five rainbow trout and two largemouth bass were captured by electrofishing (14 attempts). Fish generally did not appear to hold in the flip bucket pool, except at relatively low flows. At such low flows, relatively few fish emigrated over the spillway lip (see Discussion).

Water velocity in the reservoir's unlined spillway approach channel, 20 feet upstream of the spillway weir, is graphed over a range of spill stages in Figure 4. Figure 5 illustrates the surface water velocity at the weir, calculated from reservoir stage and known discharge over the weir's 60-foot length.

FIGURE 4. Antelope Reservoir spillway intake channel - water velocity at various spill stages.

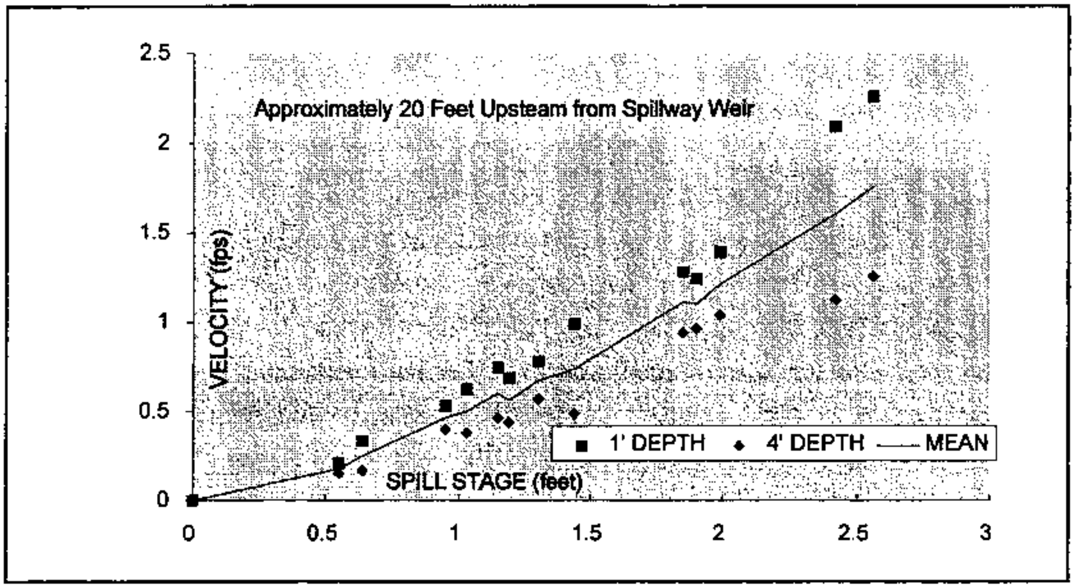
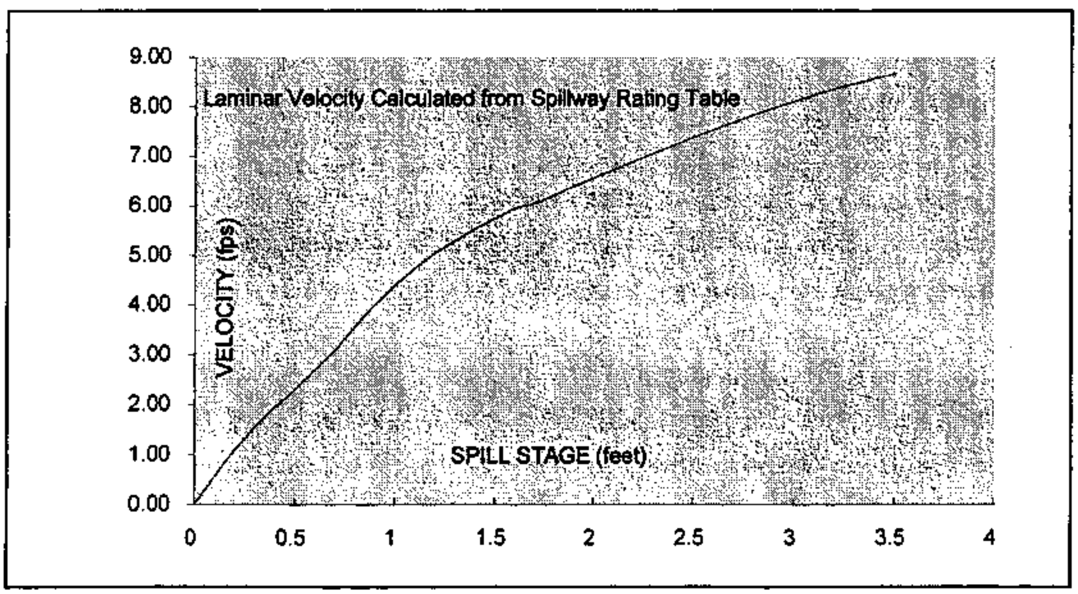


FIGURE 5. Antelope Reservoir spillway weir crest - approximate water velocity at various spill stages.



Creel Census

Indian Creek. During the 1995 Indian Creek fishing season, 256 stream anglers were contacted. They had fished 454 hours collectively, with an observed catch of 88 brown trout, 39 rainbow trout, and 2 largemouth bass. No Eastern brook trout were observed. In addition, a total of 206 other trout were reported to have been caught and released. Based on the associated recreation use survey (Rischbieter and Scott 1996), total angling use was estimated at 4,700 hours (± 1,300 hours) or about 2,100 angler days. Observed catch rates suggest an estimated catch of 800 brown trout, 500 rainbow trout, and perhaps 10 largemouth bass. As many as 3,400 additional trout may have been caught and released. Ten redear sunfish and one largemouth bass were reportedly caught and released.

The mean fork length of brown trout creeled during 1995 was 27.5 cm with a range of 15 to 36 cm. The mean length of rainbow trout was 32.9 cm with a range of 21 to 43 cm. Only one creeled fish measured, a 42 cm rainbow trout, bore any mark from the spillway study. This specimen was one of the five trout collected from the spillway pool while electroshocking (March 26); it was then collected again on April 4 while sampling fish in the channel at the reservoir's outlet valves, and then was taken by an angler on Opening Day (April 29).

About 52 percent of the anglers censused fished exclusively with bait, 2 percent with lures, and 10 percent with flies. Another 36 percent fished with some combination of these methods, mostly bait and lures.

Antelope Reservoir. A total of 248 reservoir anglers (139 shore, 109 boat) were contacted during the period of the study which coincided with the stream fishing season. They had fished 481.5 hours, with an observed catch of 72 rainbow trout, 11 brook trout, 11 largemouth bass and 3 brown bullhead. In addition, 7 largemouth bass, 6 brown bullhead, 2 rainbow trout, 2 bluegill, and 1 redear sunfish were reported to have been caught and released.

The mean fork length of rainbow trout creeled in 1995 was 39.6 cm with a range of 34 to 44 cm. The mean length of Eastern brook trout was 35.4 cm (range 32 to 38 cm). Trout caught from shore averaged slightly larger (mean 40.0 cm versus 39.5 cm), but boat anglers enjoyed a substantially greater catch per unit effort (0.21 trout per hour versus 0.08 trout/hr). About 59 percent of the anglers fished with bait, 19 percent with lures, 19 percent with a combination of bait and lures, and 3 percent with a combination of flies and lures.

Only 16 anglers were observed fishing at the reservoir between March 9 and April 28, prior to the stream fishing season and while the spillway net was in place. Varying amounts of ice were on the lake through mid-March, but conditions were no longer safe for ice-fishing; 14 anglers fished from shore and 2 anglers fished unsuccessfully from a boat. These 16 anglers fished a collective 24.5 hours and creeled 3 rainbow and 1 brook trout. However, the two boat anglers also stated they collectively caught 2 rainbow trout, 1 largemouth bass, and 1 brown trout on a day during this period prior to their interview. This anecdotal report is the only evidence that brown trout were in Antelope Reservoir during 1995.

<u>Fish Population Sampling</u>

Indian Creek (below dam). Table 2 presents the summarized results of fish population sampling in September 1995. Additionally, five rainbow trout (34.5, 25.5, 24, 19, and 18 cm fork length, respectively) and four brown trout (23.5, 25.5, 25.5, and 26 cm, respectively) were collected while spot-sampling 600-800 feet of likely habitat 0.3 miles downstream from the dam. Based on coloration, the largest and two smallest rainbow trout appeared to be planted trout escaped from the reservoir. No fish collected bore any marks from earlier study.

Outlet Valve Vicinity. Three species of fish were found in the branch of the Indian Creek channel (265 feet long) near the outlet valves immediately after the 24" valve (131 cfs) was shut off (April 4). All but one rainbow trout (of 11), all brown trout (5), and black crappie (1) were captured on the first pass, suggesting that the population

TABLE 2. Results of fish population sampling from six stations at Indian Creek, September 1995.

STATION NUMBER	DISTANCE TO DAM (miles)	STATION LENGTH (feet)	POPULATION ESTIMATES		TOTAL COLLECTED		OTHER SPECIES COLLECTED
			RT	BN	RT	BN	
1	0.8	150	0	9	0	9	None
2	2.4	181	0	44	0	43	None
3	3.1	130	0	15	0	14	None
4	4.2	220	0	55	0	50	1 CC
5	7.7	160	19	11	19	11	1 RS
6	13.1	123	9	0	9	0	30 SK, 1 SQ

KEY: RT = rainbow trout, BN = brown trout, CC = channel catfish, RS = redear sunfish, SK = Sacramento sucker, SQ = Sacramento squawfish

estimate for each species in the section was equal to the number collected. Most rainbow trout (9 of 11) measured between 11 cm and 15 cm and were identical in appearance to fingerling rainbow trout occasionally collected in the spillway. As noted above (Creel Census), one of the 11 rainbow trout was a nearly ripe female about 42 cm fork length, and bore caudal and dorsal marks indicating it had been caught by electroshocking the spillway pool 9 days earlier. In addition to the one crappie collected (9 cm fork length), many others were found dead immediately downstream from the outlet valves.

Antelope Reservoir Tributaries. The three Antelope Reservoir tributaries sampled were moderately turbid and cold (33°-35° F) at the time of sampling (0800 hours, April 19). Indian Creek, flowing at approximately 50 cfs, was the only tributary in which lakerun fish were observed; 4 large rainbow trout (26, 33, 42, and 42 cm fork length, respectively) and one large Sacramento sucker (47 cm) were collected in three separate areas. Four additional juvenile rainbow trout (1 age 0+, 3 age 1+) were also collected in Indian Creek. A total of only four juvenile rainbow trout were observed in the two smaller tributaries (Lone Rock Creek and Boulder Creek, each estimated to flow 30 cfs on April 19). It was not determined whether the juvenile trout were resident trout or lakerun progeny.

DISCUSSION AND CONCLUSIONS

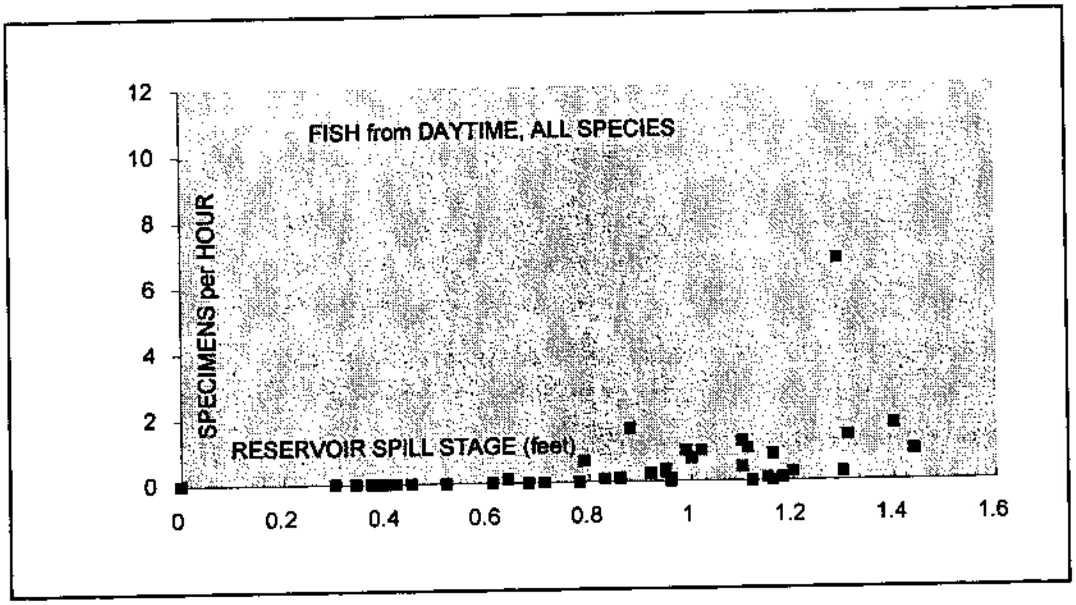
The results in Appendix A show that significantly larger quantities of fish were collected during dawn/morning checks of the spillway net than from late afternoon/early evening checks, indicating that such migration was predominantly a nocturnal phenomenon. Cumulative overnight emigration exceeded daytime emigration by more than 7 times, with varying factors for each of the six most common species (Table 3). Furthermore, a relationship exists between the number of fish emigrating over the spillway and the spill stage/flow during the study period. Figures 6A and 6B illustrate the general relationship between the emigration rate of all fish over the spillway at various spill stages during daytime and overnight hours, respectively, for all sampling which occurred no more than 19 hours after the last time the net had been emptied. Figures 7A through 7D illustrate these relationships respectively for largemouth bass, redear sunfish, black crappie, and rainbow trout.

TABLE 3. Comparison of daytime and nighttime emigration rates, Antelope Reservoir Spillway, March and April 1995.

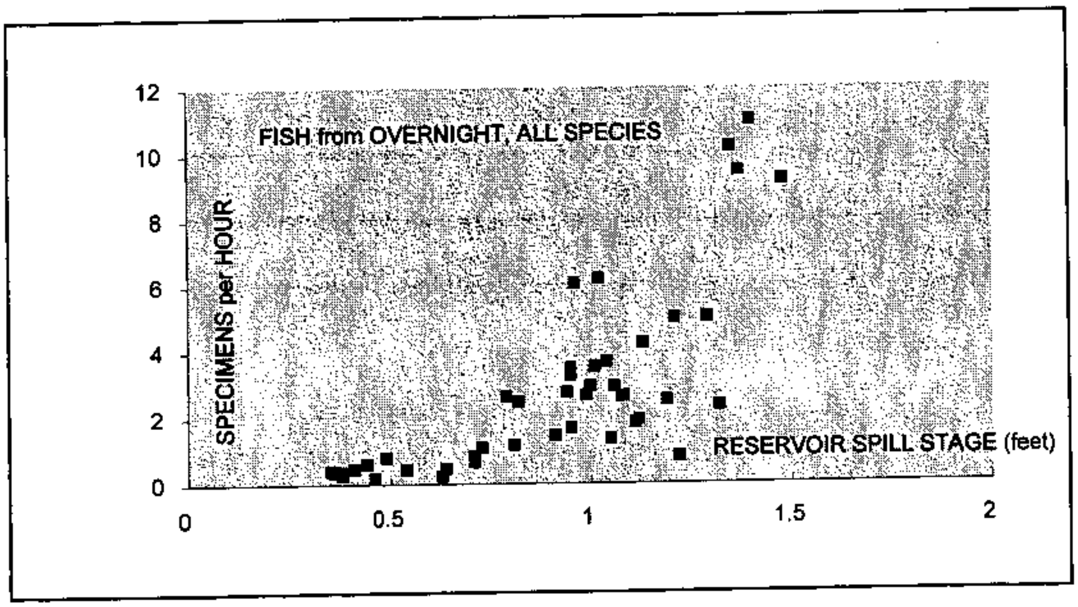
SPECIES	TOTAL COLLECTED	CONFIRMED DAYTIME	CONFIRMED NIGHTTIME	RATIO NIGHT:DAY
Largemouth Bass	928	153*	763	4.99
Redear Sunfish	634	36	489	13.58
Black Crappie	199	4	164	41.00
Rainbow Trout	115	19	66	3.47
Green Sunfish	35	2	25	12.50
Brook Trout	13	0	11	N/A
SUBTOTAL	1924	214	1518	7.09

*More than half were observed on one date (April 25).

FIGURE 6. Average emigration rate (all fish) over Antelope Reservoir spillway at various spill stages.

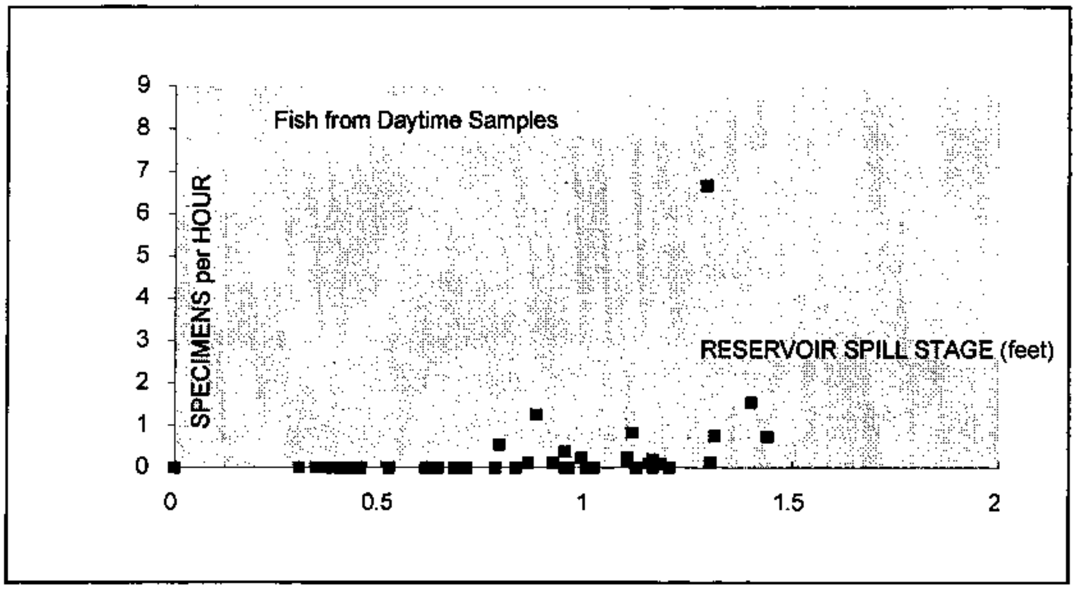


Daytime Observations

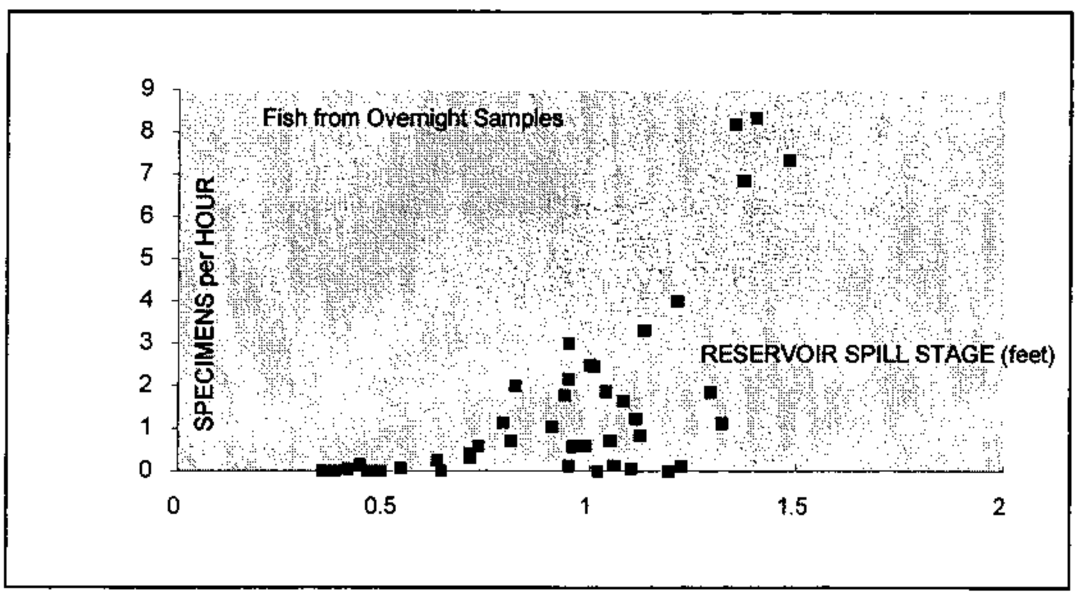


Nighttime Observations

FIGURE 7A. **Largemouth bass average emigration rates over Antelope Reservoir spillway at various spill stages.**

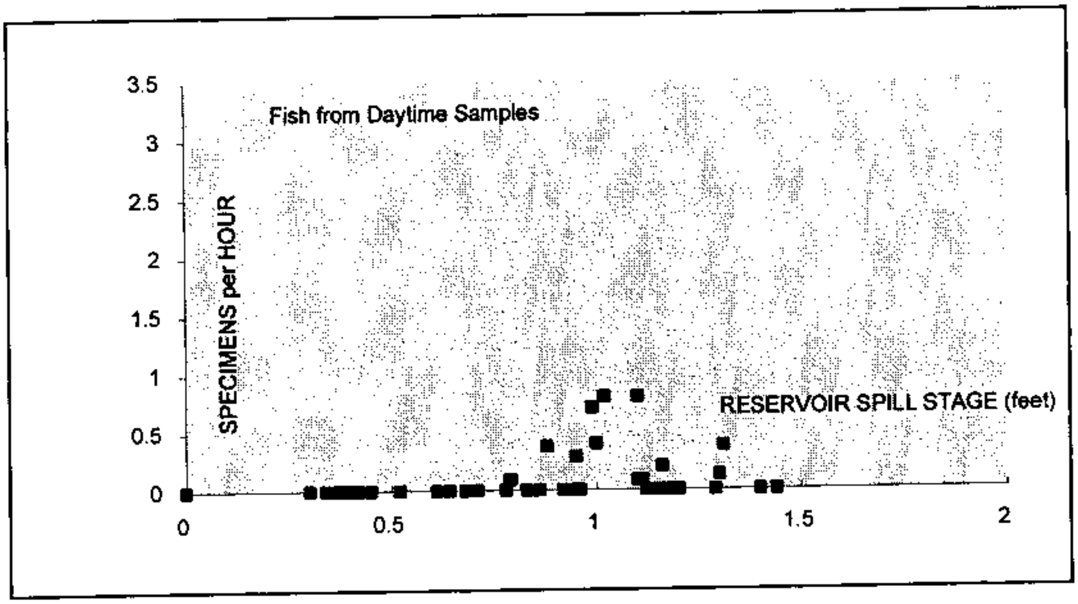


Daytime Observations

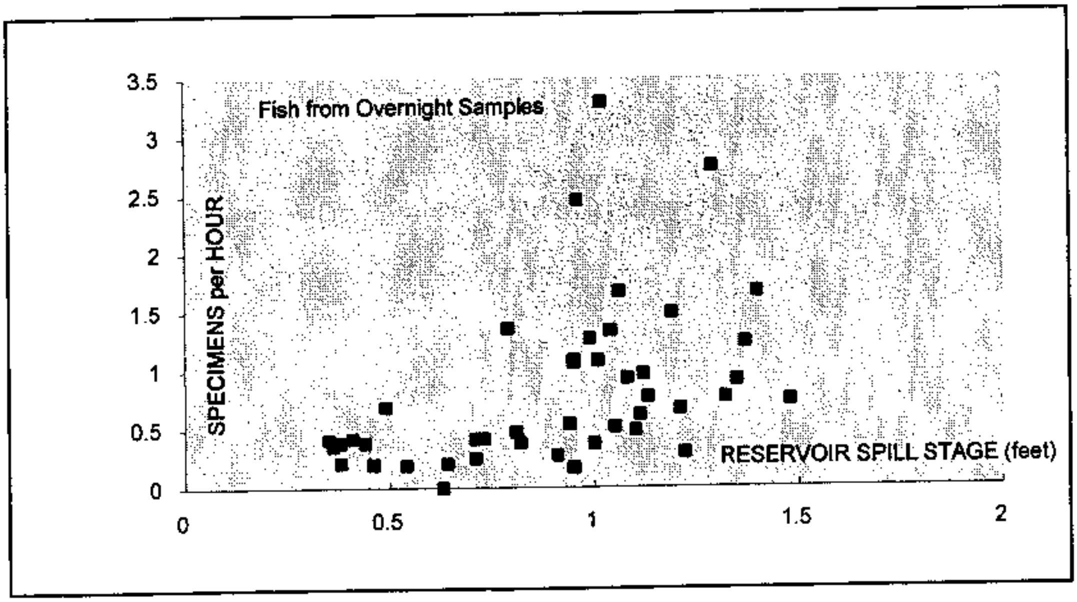


Nighttime Observations

FIGURE 7B. Redear sunfish average emigration rates over Antelope Reservoir spillway at various spill stages.

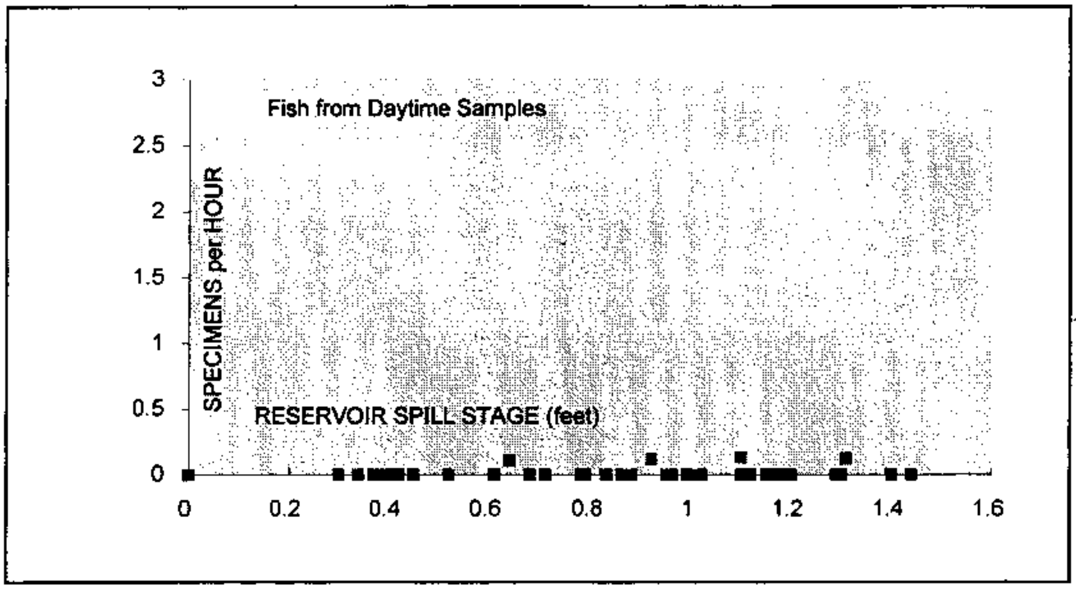


Daytime Observations

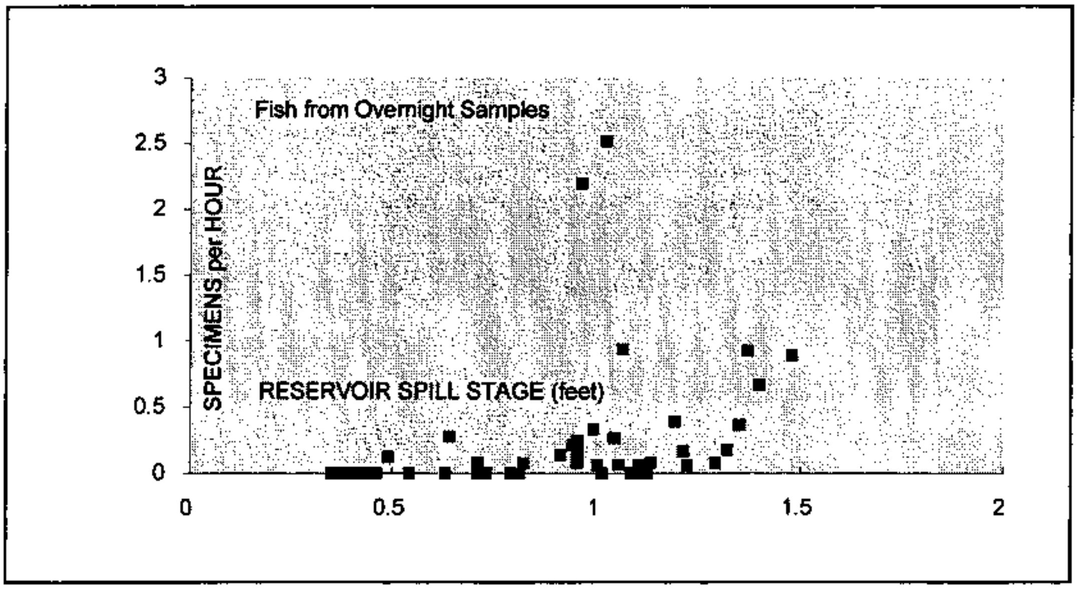


Nighttime Observations

FIGURE 7C. Black crappie average emigration rates over Antelope Reservoir spillway at various spill stages.

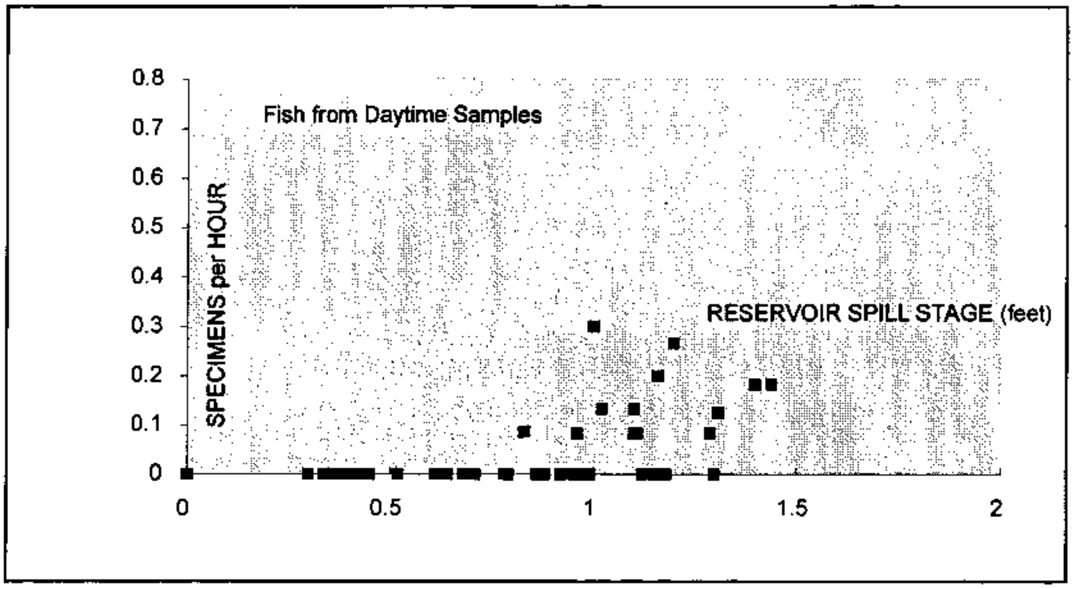


Daytime Observations

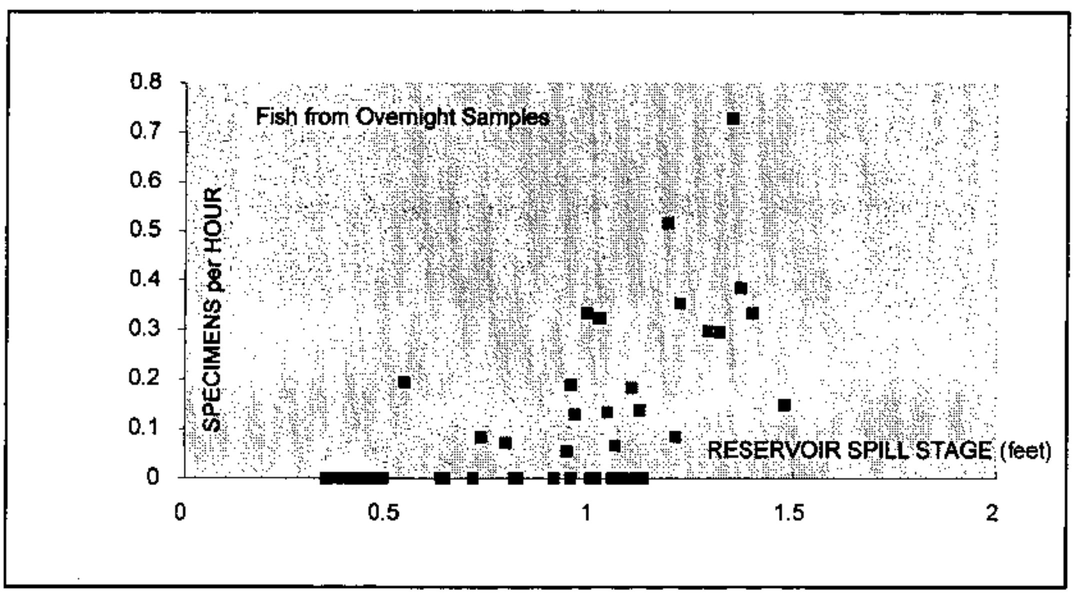


Nighttime Observations

FIGURE 7D. Rainbow trout average emigration rates over Antelope Reservoir spillway at various spill stages.



Daytime Observations



Nighttime Observations

In general, emigration of fish over the Antelope Reservoir spillway did not occur at a high rate until spill stage reached and exceeded 0.8 feet. Even under these conditions, overnight cumulative emigration exceeded daytime emigration by a factor of 6.6. Both of these generalizations are somewhat inconsistent with results and observations reported by early investigators into the spillway passage phenomenon (Clark 1942; Louder 1958; Elser 1960; Lewis et al. 1968), though they held true without exception for some species infrequently observed (e.g. brook trout, brown bullhead). However, note that an unusually high daytime emigration rate (mostly largemouth bass) was observed on April 25; no compelling explanation of this observation was apparent. Results of this study, in the context of earlier investigations, may be somewhat more accurate because most earlier studies relied on samples collected intermittently or from a fraction of the outflow area, whereas this study featured continuous collection from the entire width of the spillway.

Fish may be more prone to entrainment in spillway flows during periods of greater foraging or ranging activity. Relatively greater foraging activity at dusk, night, and/or early morning is a common behavior of most of these species. For example, redear sunfish are often underexploited by fishermen because they prefer deeper water than most sunfish, but they move into shallower (3 to 7 feet deep) areas at night (Moyle 1976). Other species, such as largemouth bass, seek water of this depth with appropriate substrate during spring periods of rising water temperature in preparation for nest-building and spawning. Although three night samples are insufficient to draw any clear conclusions about variations of emigration rates within nighttime hours, it is noteworthy that variations of the nighttime emigration rate during the dusk-midnight period and the midnight-dawn period, based on the three samplings which occurred after dark, did not show consistent patterns. Although patterns differ for each species, and some species were not present in some samplings, it appeared that both the post-dusk and pre-dawn periods were characterized by similar nighttime fish activity. Furthermore, spillway emigration did not appear to vary in relation to changes in weather, cloud cover, or lunar phase or illumination.

Several factors probably contributed to the relative abundance of largemouth bass observed leaving the reservoir. Fingerling trout, young-of-year of other game species, and minnows in general (speckled dace, hitch, Lahontan redside[?]) were undoubtedly underrepresented in the net because they were usually capable of passing through the 1.5"-mesh. It may well be that bass are the most abundant game species in the lake, although the creel census indicated that Antelope Reservoir is primarily considered a trout fishery by anglers. However, the number of trout stocked each year has generally declined (Table 4), and a large fraction of fingerlings planted in recent years are probably preyed upon by bass if the bass population is large. The unlined approach channel of the spillway appears to be a suitable site for bass spawning, in contrast to extensive adjacent areas of riprap on the dam embankments; this alone may have selectively attracted bass toward an area where they were vulnerable to being washed over the weir. (The velocities reported in Figure 4 are not sufficient to overwhelm most fish, but velocity increases rapidly at and beyond the weir [Figure 5].)

Largemouth bass emigration also increased in frequency as the study progressed, when spill stage was above 0.8 feet. This appeared to be related to seasonal progression and/or warming of the surface water (Figure 8; Appendix A) which generally advanced concurrently. Although most temperatures observed were below the temperatures associated with initiation of spawning cited by Moyle (1976), April is commonly the beginning of such activity. During the period of spillway netting an estimated 700 pounds of bass left the reservoir; total bass biomass lost was probably double or triple this after the net was removed.

Anecdotal reports and creel censuses (Rischbieter and Scott 1996; Scott 1994) suggest that fewer trout passed over the spillway during 1995 and 1993 than had in earlier years (Cartier 1979b; Haines 1981b; Hinton 1983; Tittel 1987). This is probably partially due to decreasing size of the trout population of the reservoir, in turn related to reductions in annual trout plants (Table 4). Relatively low catch rates for reservoir anglers, observed in the 1995 creel

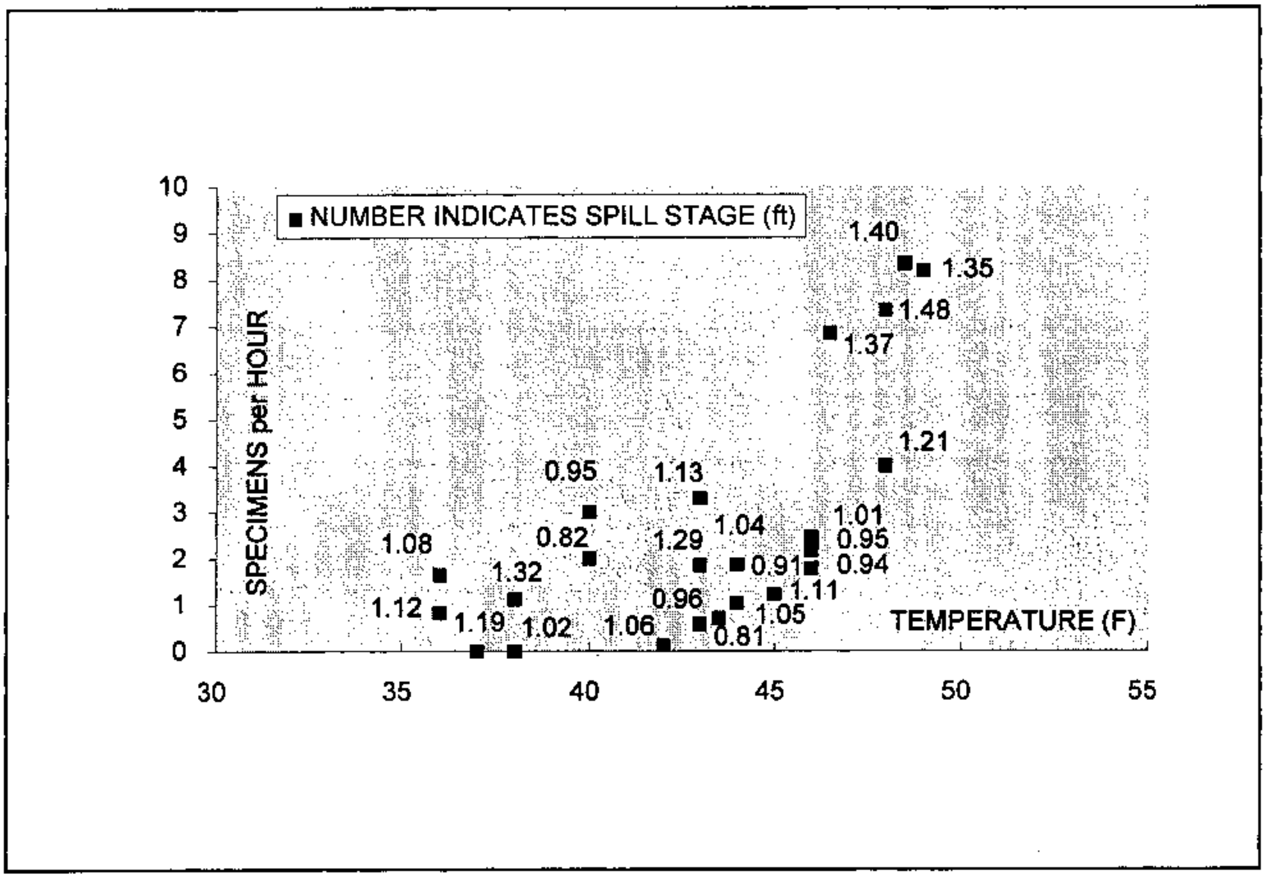
TABLE 4. Antelope Reservoir trout planting record summary, 1976-1995.

YEAR	RAINBOW TROUT			EASTERN BROOK TROUT	
	Catchable	Subc'able	Fingerling	Catchable	Subc'able
1976	No planting due to Rotenone treatment.				
1977	15,000	0	69,000	0	0
1978	0	0	250,000	0	0
1979	15,000	8,000	285,890	0	0
1980	13,440	19,920	150,000	0	0
1981*	30,980	72,000	100,000	0	0
1982	30,000	0	50,000	0	0
1983¤	30,000	0	50,000	0	0
1984	30,000	0	0	0	0
1985¤	37,015	0	0	0	0
1986	31,000	0	0	0	0
1987	25,200	0	0	0	0
1988	35,400	0	0	0	0
1989¤	31,200	0	0	0	0
1990	16,240	84,800	60,000	6,000	0
1991	16,170	0	0	4,700	0
1992	7,650	0	0	22,600	0
1993	9,500	32,500	0	11,500	17,700
1994	9,600	0	46,969	7,600	0
1995	4,624	0	0	0	0

*Only recorded black bass introductions: 912 smallmouth, 99 largemouth

¤Brown trout plants (catchable): 1983- 10,000; 1985- 6,000; 1989- 5,010

FIGURE 8. **Nighttime largemouth bass emigration rates versus water temperature** (at spill stages >0.8 feet).



census, also reflect a decrease. Additional evidence includes anecdotal reports from anglers suggesting that fishing has significantly deteriorated over the previous three years. Antelope Reservoir had been a popular and successful ice-fishing site for some local anglers, but public interest deteriorated after poor success in 1993 and 1994 (L. Kingdon, pers. comm.). Because of reduced trout planting (Table 4), and in the context of the thriving wild brown trout fishery in Indian Creek, it appears that mature rainbow trout would be more valuable from both a fishery and recreational perspective if they were retained in Antelope Reservoir and/or encouraged to spawn in the reservoir's tributaries.

An initial premise of this investigation, that spawning rainbow trout are attracted to the spillway flows in their search for spawning habitat, is partially supported by the relative frequency of rainbow versus brook trout observed in the net. Nine times as many rainbow trout as brook trout were observed in the spillway, but recent planting allotments (Table 4) suggest that the rainbow trout population is less than twice as large as the brook trout population. This deduction is based on an assumption that both species survive and persist at similar rates, and disregards natural/wild reproduction, but cannot be dismissed based on 1995 reservoir creel census results (which suggest a population ratio intermediate between the above extremes).

Most non-salmonid species in Antelope Reservoir generally fail to contribute to the sport fishery. Most bass were of similar size and therefore of the same cohort which, based on size (Moyle 1976), are probably in their third year. Prior to 1995, relatively few of these bass would have been large enough to encourage anglers (there is no minimum size limit at Antelope Reservoir), so a reputation as a bass fishery would be unlikely to develop. Redear sunfish, probably because of their predisposition to deeper water, and black crappie are also generally absent from the creel. Their abundance in the spillway suggests that these species are thriving and likely competing with trout for food, habitat, and other resources of the lake.

The unusually low catch of reservoir-origin rainbow (and brook) trout by Indian Creek anglers during 1995 (Rischbieter and Scott 1996) is also due to several factors in addition to those mentioned above, as is the minimal recovery of all fish marked during the spillway study. The highest flow ever recorded in the Antelope Dam spillway occurred on May 1, 1995 (stage 3.26', approximately 1200 cfs), two days after the commencement of fishing season. Even prior to this event, and for several weeks thereafter, flows in Indian Creek were too high for normal fishing. As such, fishing use and success were very low for several weeks during the early season (usually the most popular, promising, and successful time); this is corroborated by reduced fishing hours and brown trout (resident) catch observed in the 1995 recreation survey/creel census. Prior to the opening of the season, only 38 of 115 rainbow and 1 of 13 brook trout survived the spillway collection and were marked and released into the creek. This "maximum available population" on opening day was smaller than the actual catch observed on opening weekend in 1993 (Scott 1994). High flows also likely distributed fish farther downstream, especially sunfish which would find little habitat upstream of Genesee Valley during high flows. Genesee Valley and points downstream receive sparse fishing pressure; the creel census included only six miles of Indian Creek in this area, this stretch received only about 500 hours of fishing effort in 1995, and only 46.5 hours of this effort were censused.

Unmarked rainbow trout of apparent reservoir origin, caught by anglers and biologists later in 1995, almost certainly emigrated following the removal of the spillway net. Spill stages greater than 0.8 feet persisted for more than two full months following the removal of the net; under these conditions, it seems reasonable that an average of several trout per day entered Indian Creek. However, it is not readily discernable how the migration rate might increase during spill stages greater than 2.0 feet, as these flows were well beyond the range of conditions encountered during trapping. Such flows during May did likely pass the extremely large channel catfish into Indian Creek, a species otherwise not observed in the spillway or the creek.

Some discussion of the feasibility of the spillway net and collection method is also appropriate, both in the context of the range of environmental conditions and the effect on aquatic species. The collection methods used in the spillway became impractical and even dangerous at spill stages above 1.5 feet (300 cfs), making it fortunate that extreme flow conditions were not persistent until after the net was removed. High flows and certain winds increased the amount and size of debris in the net; occasionally it was necessary to preemptively remove logs and other large items from the floating boom upstream from the spillway.

Even within safe ranges of conditions, there was progressively higher mortality of fish as flows increased and/or the period between checks of the net lengthened. The mortality rate induced by the net on most species was unacceptably high, discouraging the desirability of repeating this investigation without some modification of equipment and/or sampling schedule. Because of a bow and "sunken pocket" which developed in the net under the pressure of flow and debris, fish could not escape the net once impinged. A more rigid overhead suspension of the net could eliminate some of this problem, allowing some fish to avoid impingement until being herded at collection time. Checking the net more often, perhaps six times per day and night instead of twice, could also greatly diminish mortality. Late-season snowfall was one factor which occasionally delayed travel to Antelope Reservoir, but checking the net more frequently was generally not practicable given available personnel.

It should be noted that most of the mortality observed during the spillway study involved species which do not contribute to the Indian Creek sport fishery and, given the extreme high water of 1995, probably would not have remained (or survived) in Indian Creek if undisturbed. The mortality of at least 89 trout during the course of this study, while unfortunate, occurred over a period of 50 days. Thus, trout mortality probably did not have a significant or lasting impact on the Indian Creek fishery considering the record high flows, later emigration, and low fishing pressure which occurred during May. Conversely and ironically, if there had been a larger trout population in the reservoir, and high trout emigration rates as suggested by observations in past years, response to the mortality rate would have necessarily been immediate modification or termination of collection.

Although results related to the influence of spill stage on the fish emigration rate are somewhat inconsistent with results and observations reported by early investigators (Clark 1942; Louder 1958; Elser 1960; Lewis et al. 1968), they suggest that spill manipulation/limitation may be a potential management tool when prevention of reservoir fish loss is desired. Some management efforts toward that end have occurred using nets across outflow areas, instead of spill manipulation, at other reservoirs (Stober et al. 1983) including nearby Lake Davis. Conversely, increasing spill by limiting bypass/valve outflows could be used to encourage relocation of fish from a reservoir into downstream areas. While a small reservoir in a large watershed, such as Antelope Reservoir, is not a particularly suitable candidate for this type of management strategy, many other State and other reservoirs are not similarly constrained.

In the case of Lake Davis, the observations discussed above are generally of immediate interest because of the State's desire to prevent northern pike from leaving Lake Davis via Big Grizzly Creek. Lake Davis spill did not exceed 0.21 feet in Spring 1995, suggesting that pike had little opportunity to enter Big Grizzly Creek. This is supported by Fall 1995 fish population sampling of Big Grizzly Creek (Brown 1996), although it should be noted that a black crappie collected from the channel at the Antelope Dam valves probably survived passage through a 24" valve and appurtenant energy-dissipator. In addition to the one crappie collected alive, many additional juvenile crappie appeared to have died from encountering the Antelope valve, indicating that some species are common in the profundal zone and prone to entrainment in deepwater outflow. Similar valves at Grizzly Valley Dam (Lake Davis) may allow fish passage into Big Grizzly Creek, but Stier and Kynard (1986) cited that larger fish have a higher mortality rate when passed through valves and other mechanical features. Pike present in Spring when the large Grizzly Valley Dam valve is often open to avoid spill are likely to be substantially larger than the juvenile crappie observed at the Antelope Dam valve, and therefore less likely to survive passage through the valve and associated encounter with the energy-dissipation structure. To reduce the likelihood of future downstream pike movement, some modification of the Lake Davis outlet, such as installation of a screen or fish-killing device, may be desirable if feasible.

While it is not unusual to operate reservoirs so as to avoid spill altogether, these findings suggest that coordination of such operations can be a fishery management tool in addition to a water management tool. While the phenomenon of fish emigration may differ among other species, geographic location, and facilities, the reported results are reasonably applicable to all three of the Department's Upper Feather River reservoirs. Further study is warranted, as is dissemination of these findings among other reservoir and fishery managers.

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APPENDIX A

Collection Record Summary for each Spillway Sampling Episode

ANTELOPE DAM SPILLWAY
1995 COLLECTION SUMMARY

SKY KEY:
CL=CLEAR
CY=CLOUDY
PC=PARTLY CLOUDY
SH=SHOWERS
RN=RAIN
SN=SNOW

LUNAR KEY:
0=DARK NIGHT
1=STARLIGHT or MINIMAL MOONLIGHT
2=SOME MOONLIGHT
3=MODERATE BRIGHTNESS
4=MOSTLY MOONLIT
5=-FULL MOONLIGHT

E* = DAILY SPECIES TOTALS BASED ON ESTIMATED TIME OF DEATH

TOTAL FISH: 1940

RECORD NUMBER	DATE 1995	TIME	HOURS ELAPSED	SPILLWAY GAGE	FLOW (cfs)	PROXIMAL VELOCITY (fps)	LUNAR PHASE	SKY	AIR TEMP	WATER TEMP	RAINBOW TROUT	BROOK TROUT	BLUEGILL	L'MOUTH BASS	REDEAR SUNFISH	GREEN SUNFISH	BLACK CRAPPIE	BROWN BULLHEAD	HITCH	SPECKLED DACE	CRAYFISH	MAMMALS	BIRDS
COLUMN SUBTOTALS:											115	13	7	928	634	35	199	6	2	1	44	11	3
0	3-9	1700	0	0.00	0	0	0	RN			0	0	0	0	0	0	0	0	0	0	0	0	0
1	3-10	930	16.5	1.10	161	0.56	0	RN			3	0	3	1	8	0	1	0	0	0	0	0	0
E*	3-11	N/A	24	1.71	388	0.95		RN			3	0	0	0	0	0	0	0	0	0	0	0	0
E*	3-12	N/A	24	1.45	279	0.75		RN			7	2	0	1	0	0	2	0	0	0	0	0	0
2	3-13	1600	30	1.33	234	0.63		SH			6	0	2	0	10	0	0	1	0	0	1	0	0
3	3-14	900	17	1.22	197	0.6	2	SH			6	0	0	2	5	0	1	0	0	0	0	0	0
4	3-14	1630	7.5	1.20	191	0.58		SH			2	0	0	0	0	0	0	0	0	0	0	0	0
5	3-15	800	15.5	1.19	187	0.58	3	CL	28	37	8	2	0	0	23	0	6	0	0	0	0	0	0
6	3-15	1800	10	1.16	178	0.57		CL			2	0	0	2	2	2	0	0	1	0	0	0	0
7	3-16	900	15	1.06	151	0.52	3	CY	40	42	1	0	0	2	25	2	14	0	1	0	0	0	0
8	3-16	1630	7.5	1.02	142	0.51		CL	52	46	1	0	0	0	6	0	0	0	0	0	0	0	0
9	3-17	800	15.5	0.96	129	0.4	5	PC	30	43	2	0	0	9	38	11	34	0	0	1	0	1	0
10	3-17	1500	7	0.95	127	0.4		CY	54		0	0	0	0	2	0	0	0	0	0	0	0	0
11	3-18	700	16	0.95	127	0.4	3	RN	48		3	0	1	2	17	0	4	0	0	0	0	0	0
12	3-18	1700	10	1.00	138	0.45		PC			3	0	0	0	4	0	0	0	0	0	0	0	0
13	3-19	800	15	0.99	136	0.45	4	CL	55		5	2	0	9	19	0	5	0	0	0	0	0	0
14	3-19	1530	7.5	1.10	140	0.56		CY			1	0	0	1	6	0	1	0	0	0	0	0	0
15	3-20	1430	23	1.10	161	0.56		SN			9	0	0	6	19	0	4	1	0	0	0	0	0
16	3-21	1600	25.5	1.12	166	0.58		SN			2	0	0	3	45	9	7	0	0	0	0	0	0
17	3-22	730	15.5	1.02	142	0.46	0	SN	28	38	5	1	0	0	51	0	39	1	0	0	1	0	0
18	3-24	1630	57	0.75	87	0.3		SN	30	39	3	0	0	2	31	3	18	0	0	0	0	0	1
19	3-25	700	14.5	0.64	67	0.24	2	CL	24	38	0	0	0	0	3	0	4	0	0	0	1	0	0
20	3-25	1600	9	0.64	67	0.24		CL	32	37.5	0	0	0	0	0	0	1	0	0	0	0	0	0
21	3-26	730	15.5	0.54	51	0.18	1	CL	18	37.5	3	0	0	1	3	0	0	0	0	0	0	0	0
22	3-26	1600	8.5	0.52	48	0.18		CL	34	38	0	0	0	0	0	0	0	0	0	0	0	0	0
23	3-27	700	15	0.46	40	0.13	1	CL	19	37	0	0	0	0	3	0	0	0	0	0	0	0	0
24	3-27	1700	10	0.38	29	0.1		CL	38	40	0	0	0	0	0	0	0	0	0	0	0	0	0
25	3-28	700	14	0.38	29	0.1	1	CL	24.5	39	0	0	0	0	3	1	0	0	0	0	0	0	0
26	3-28	1630	9.5	0.40	32	0.11		CL	36	42	0	0	0	0	0	0	0	0	0	0	0	0	0
27	3-29	700	14.5	0.35	26	0.09	0	CL	25	40	0	0	0	0	6	0	0	0	0	0	0	0	0
28	3-29	1700	10	0.34	24	0.09		CL	40	42	0	0	0	0	0	0	0	0	0	0	0	0	0
29	3-30	630	13	0.36	29	0.1	0	CL	29	39	0	0	0	0	5	0	0	0	0	0	0	0	0
30	3-31	700	24.5	0.27	17	0.08	0	CL	34	44	0	0	0	0	4	0	0	0	0	0	0	0	0
31	3-31	1700	10	0.30	20	0.08		CY	53	42	0	0	0	0	0	0	0	0	0	0	0	0	0
32	4-1	700	14	0.36	27	0.09	0	RN	40	43	0	0	0	0	5	0	0	0	0	0	0	0	0
33	4-1	1500	8	0.37	28	0.1		CL	59	40	0	0	0	0	0	0	0	0	0	0	0	0	0
34	4-2	1100	19	0.41	33	0.12	0	CL			0	0	0	1	8	0	0	0	0	0	0	0	0
35	4-2	1800	7	0.42	34	0.12		CL	43	43	0	0	0	0	0	0	0	0	0	0	0	0	0
36	4-3	700	13	0.44	37	0.13	0	CL	26	43	0	0	1	2	5	0	0	0	0	0	0	0	0
37	4-3	1600	9	0.45	38	0.13		CL	67	47.5	0	0	0	0	0	0	0	0	0	0	0	0	0
38	4-4	800	16	0.49	44	0.15	1	CL	35	44	0	0	0	0	11	0	2	0	0	0	2	0	0
39	4-4	1700	9	0.61	62	0.2		PC	58	41	0	0	0	0	0	0	0	0	0	0	0	0	0

39	4-4	1700	9	0.61	62	0.2		PC	56	41	0	0	0	0	0	0	0	0	0	0	0	0	0
40	4-5	700	14	0.79	94	0.33	1	CY	32	43	1	0	0	18	19	1	0	0	0	0	3	0	0
41	4-5	1600	9	0.86	108	0.35		CY	54	41	0	0	0	1	0	0	0	0	0	0	0	0	0
42	4-6	700	15	1.04	147	0.47	1	SH	38	44	2	0	0	28	20	1	4	0	0	0	3	0	0
43	4-6	1730	10.5	1.15	175	0.58		SH	43	41	0	0	0	1	0	0	0	0	0	0	3	0	0
44	4-7	700	13.5	1.29	220	0.62	1	RN	37	43	4	0	0	25	37	1	1	1	0	0	0	0	0
45	4-7	1500	8	1.30	224	0.62		RN	44	41	0	0	0	1	1	0	0	0	0	0	0	2	0
46	4-8	800	17	1.32	231	0.63	2	SN	34	38	5	0	0	19	13	0	3	0	0	0	0	0	0
47	4-8	1600	8	1.31	227	0.63		SN	32	36	1	0	0	6	3	0	1	0	0	0	0	0	0
48	4-9	630	14.5	1.12	166	0.56	2	CY	26	36	2	0	0	12	14	0	0	0	0	0	0	0	0
49	4-9	1700	10.5	1.18	184	0.58		CY	38	40	0	0	0	1	0	0	0	0	0	0	0	0	0
50	4-10	700	14	1.08	158	0.54	3	CL	24	36	0	1	0	23	13	0	0	0	0	0	0	0	0
51	4-10	1530	8.5	0.99	138	0.45		CL	54	50	0	0	0	2	6	0	0	0	0	0	1	1	0
52	4-11	1000	18.5	0.94	125	0.4		PC	48	46	1	0	0	33	10	3	4	0	0	0	3	1	0
53	4-11	1830	8.5	0.92	121	0.38		PC	50	43	0	0	0	1	0	0	1	0	0	0	0	0	0
54	4-12	630	12	0.95	127	0.4	3	PC	33	46	0	1	0	28	13	0	2	0	0	0	4	1	0
55	4-12	1830	12	0.96	129	0.4		SH	49	46	1	0	0	0	0	0	0	0	0	0	0	0	0
56	4-13	100	6.5	1.01	140	0.45	1	RN	37	46	0	0	0	16	7	0	0	0	0	0	0	0	0
57	4-13	730	6.5	1.11	163	0.56	1	SN	31	45	0	0	0	8	4	0	0	0	0	0	3	0	0
58	4-13	1800	10.5	1.16	178	0.58		SN	31	41	0	0	0	0	0	0	0	0	0	0	3	0	0
59	4-14	700	13	1.13	169	0.57	5	PC	22	43	0	0	0	43	10	1	1	0	0	0	3	0	0
60	4-14	1500	8	1.12	166	0.57		PC	41	45	0	0	0	0	0	0	0	0	0	0	0	0	0
61	4-15	700	16	1.00	138	0.45	5	SH			0	0	0	40	6	0	1	0	0	0	0	0	0
62	4-15	1900	12	1.10	161	0.56		SN	33	38	1	0	0	3	1	0	0	0	0	0	0	0	0
63	4-16	700	12	0.95	127	0.4	5	CL	38	40	0	0	0	36	2	0	1	0	0	0	0	0	0
64	4-16	1400	7	0.96	129	0.4		CY	49	41	0	0	0	0	0	0	0	0	0	0	0	0	0
65	4-16	2200	8	0.88	112	0.35	2	CY	33	38	0	0	0	10	3	0	0	0	0	0	0	0	0
66	4-17	1100	13	0.82	100	0.32	1	CY	50	40	0	0	0	26	5	0	1	0	0	0	4	0	0
67	4-17	2200	11	0.79	94	0.3	1	SH	34	44	0	0	0	6	1	0	0	0	0	0	0	0	1
68	4-18	630	8.5	0.81	98	0.31	2	SN	29	43.5	0	0	0	6	4	0	0	0	0	0	0	0	0
69	4-18	1900	12.5	0.78	93	0.3		PC	37	45	0	0	0	0	0	0	0	0	0	0	0	0	0
70	4-19	700	12	0.73	83	0.28	3	PC	21	43	1	0	0	7	5	0	0	0	0	0	0	0	0
71	4-19	1900	12	0.71	80	0.26		CY	38	40	0	0	0	0	0	0	0	0	0	0	1	0	0
72	4-20	700	12	0.71	80	0.26	1	SN	28	41	0	0	0	5	3	0	0	0	0	0	2	0	0
73	4-20	1500	8	0.71	80	0.26		SH	37	43	0	0	0	0	0	0	0	0	0	0	0	0	0
74	4-21	700	16	0.63	66	0.22	3	CL	40	42	0	0	0	4	0	0	0	0	0	0	0	0	0
75	4-21	1830	11.5	0.68	74	0.25		CL	48	44	0	0	0	0	0	0	0	0	0	0	0	0	0
76	4-22	630	12	0.71	80	0.26	3	CL	37	44	0	0	0	4	5	0	1	0	0	0	1	0	0
77	4-22	1800	11.5	0.83	102	0.32		CL	58	48	1	0	0	0	0	0	0	0	0	0	0	0	0
78	4-23	630	14.5	0.91	119	0.38	2	CL	38	44	0	0	0	15	4	0	2	0	0	0	0	0	0
79	4-23	1630	8	0.95	127	0.4		CL	50	46	0	0	0	3	0	0	0	0	0	0	0	0	0
80	4-24	800	15.5	1.05	149	0.45	2	CL	38	43.5	0	1	0	11	8	0	1	0	0	0	0	0	0
81	4-24	2000	12	1.11	163	0.56		CL	51	43	1	0	0	10	1	0	0	0	0	0	2	1	0
82	4-25	800	12	1.21	194	0.6	2	CL	34	48	1	1	0	48	8	0	2	0	0	0	2	2	0
83	4-25	2000	12	1.29	220	0.62		CL	54	45	1	0	0	80	0	0	0	0	0	0	1	0	0
84	4-26	130	5.5	1.35	242	0.7	1	CL	34	49	4	0	0	45	5	0	2	1	0	0	0	0	0
85	4-26	730	6	1.40	260	0.75	1	CL	34	48.5	2	0	0	50	10	0	4	1	0	0	1	1	0
86	4-26	1830	11	1.40	260	0.75		PC	54	47	2	0	0	17	0	0	0	0	0	0	0	0	0
87	4-27	800	13.5	1.48	290	0.78	1	PC	44	48	2	1	0	99	10	0	12	0	0	0	0	0	0
88	4-27	1900	11	1.44	275	0.73		RN	39	44	2	0	0	8	0	0	0	0	0	0	0	0	1
89	4-28	800	13	1.37	249	0.7	0	RN	36	46.5	5	1	0	89	16	0	12	0	0	0	2	1	0

APPENDIX B

1995 Indian Creek Creel Census Schedule

RECREATION SURVEY SCHEDULE FOR
INDIAN CREEK, PLUMAS COUNTY
APRIL 29, 1995, TO NOVEMBER 15, 1995

Indian Creek Survey Dates	Holiday = HD Weekend = WE Weekday = WD	Survey Strata
April 29	WE	I
April 30	WE	I
May 1	WD	III
May 14	WE	IV
May 18	WD	III
May 27	HD	II
May 28	HD	II
June 4	WE	IV
June 17	WE	IV
June 23	WD	III
June 24	WE	IV
June 29	WD	III
July 1	HD	IX
July 4	HD	IX
July 6	WD	V
July 15	WE	VI
July 24	WD	V
July 30	WE	VI
August 6	WE	VI
August 9	WD	V
August 23	WD	V
September 3	HD	IX
September 8	WD	VII
September 17	WE	VIII
October 5	WD	VII
October 7	WE	X
October 8	WE	X
October 21	WE	VIII
October 28	WE	VIII
November 9	WD	VII

CONVERSION FACTORS

Quantity	To convert from customary unit	To metric unit	Multiply customary unit by	To convert to customary unit, multiply metric unit by
Length	inches (in)	millimeters (mm)*	25.4	0.03937
	inches (in)	centimeters (cm)	2.54	0.3937
	feet (ft)	meters (m)	0.3048	3.2808
	miles (mi)	kilometers (km)	1.6093	0.62139
Area	square inches (in^2)	square millimeters (mm^2)	645.16	0.00155
	square feet (ft^2)	square meters (m^2)	0.092903	10.764
	acres (ac)	hectares (ha)	0.40469	2.4710
	square miles (mi^2)	square kilometers (km^2)	2.590	0.3861
Volume	gallons (gal)	liters (L)	3.7854	0.26417
	million gallons (10^6 gal)	megaliters (ML)	3.7854	0.26417
	cubic feet (ft^3)	cubic meters (m^3)	0.028317	35.315
	cubic yards (yd^3)	cubic meters (m^3)	0.76455	1.308
	acre-feet (ac-ft)	thousand cubic meters ($m^3 \times 10^3$)	1.2335	0.8107
	acre-feet (ac-ft)	hectare-meters (ha – m)▪	0.1234	8.107
	thousand acre-feet (taf)	million cubic meters ($m^3 \times 10^6$)	1.2335	0.8107
	thousand acre-feet (taf)	hectare-meters (ha – m)▪	123.35	0.008107
	million acre-feet (maf)	billion cubic meters ($m^3 \times 10^9$)♦	1.2335	0.8107
	million acre-feet (maf)	cubic kilometers (km^3)	1.2335	0.8107
Flow	cubic feet per second (ft^3/s)	cubic meters per second (m^3/s)	0.028317	35.315
	gallons per minute (gal/min)	liters per minute (L/min)	3.7854	0.26417
	gallons per day (gal/day)	liters per day (L/day)	3.7854	0.26417
	million gallons per day (mgd)	megaliters per day (ML/day)	3.7854	0.26417
	acre-feet per day (ac-ft/day)	thousand cubic meters ($m^3 \times 10^3$/day)	1.2335	0.8107
Mass	pounds (lb)	kilograms (kg)	0.45359	2.2046
	tons (short, 2,000 lb)	megagrams (Mg)	0.90718	1.1023
Velocity	feet per second (ft/s)	meters per second (m/s)	0.3048	3.2808
Power	horsepower (hp)	kilowatts (kW)	0.746	1.3405
Pressure	pounds per square inch (psi)	kilopascals (kPa)	6.8948	0.14505
	feet head of water	kilopascals (kPa)	2.989	0.33456
Specific capacity	gallons per minute per foot of drawdown	liters per minute per meter of drawdown	12.419	0.08052
Concentration	parts per million (ppm)	milligrams per liter (mg/L)	1.0	1.0
Electrical conductivity	micromhos per centimeter	microsiemens per centimeter (µS/cm)	1.0	1.0
Temperature	degrees Fahrenheit (°F)	degrees Celsius (°C)	(°F – 32)/1.8	(1.8 x °C) + 32

* When using "dual units," inches are normally converted to millimeters (rather than centimeters).

▪ Not used often in metric countries, but is offered as a conceptual equivalent of customary western U.S. practice (a standard depth of water over a given area of land).

♦ ASTM Manual E380 discourages the use of billion cubic meters since that magnitude is represented by *giga* (a thousand million) in other countries. It is shown here for potential use for quantifying large reservoir volumes (similar to million acre-feet).